85-4001

HYDROGEOLOGY OF THE CROSS BAR RANCH WELL-FIELD AREA AND PROJECTED IMPACT OF PUMPING, PASCO COUNTY, FLORIDA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4001

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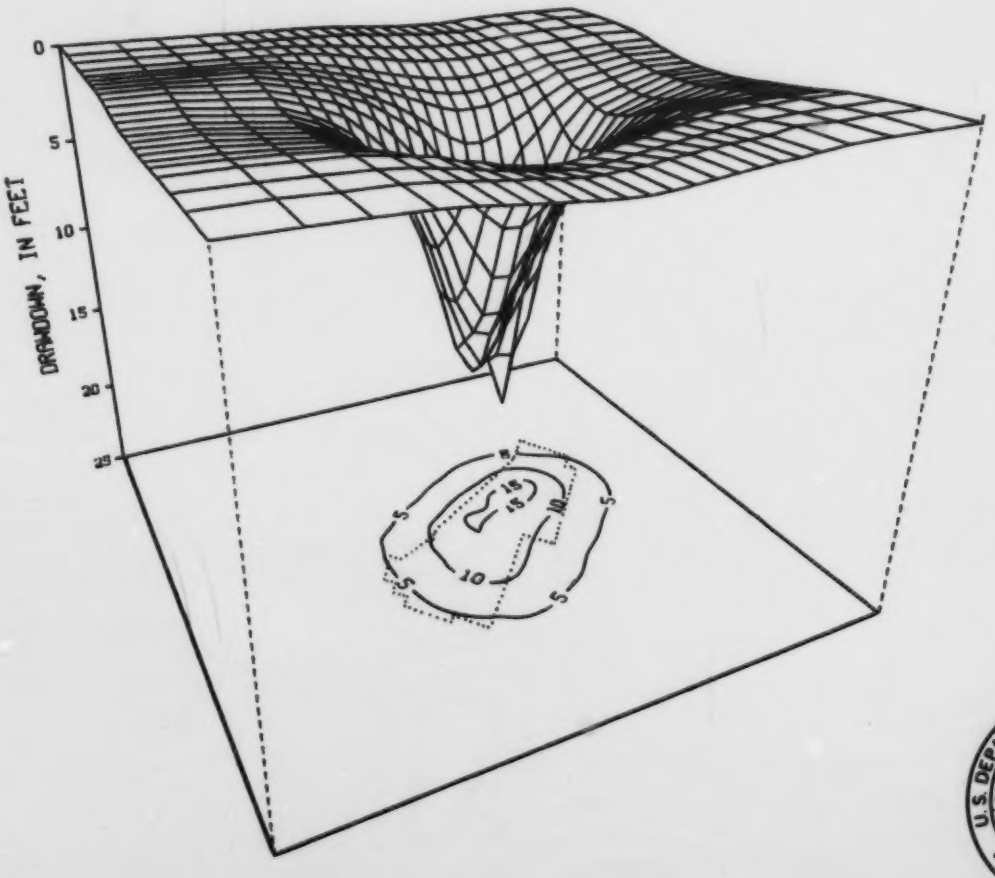

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By C. B. Hutchinson

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Tallahassee, Florida

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

	Page
Abstract	1
Introduction	2
Purpose and scope	2
Approach	3
Previous investigations	4
Acknowledgments	4
Hydrogeologic framework	4
Physical setting	4
Aquifers and confining units	5
Hydraulic characteristics	7
Ground-water levels and movement	15
Hydrologic anomaly	17
Surface water-ground water relations	23
Ground-water quality	26
Hydrologic cycle	28
Conceptual model	30
Simulated impact of pumping	33
Predevelopment conditions, with no pumping	35
Regional pumping adjacent to Cross Bar Ranch	35
Pumping 30 million gallons per day	40
Pumping 45 million gallons per day	41
Summary and conclusions	41
Selected references	51
Supplemental data: modeling procedures	55
Model grid	55
Boundary conditions	58
Input parameters	63
Calibration	71
Validation	74
Sensitivity analysis	75
Limitations of model application	79
Listing of model-input data	80

ILLUSTRATIONS

	Page
Figures 1-3. Maps showing:	
1. Location of the Cross Bar Ranch well field and study area	3
2. Physiography of the well-field area	6
3. Locations of data-collection sites	10
4. Diagram showing hydrogeologic section	11
5. Map showing pumping test sites and values of transmissivity and leakance	12
6. Map showing specific capacities of wells tapping the Upper Floridan aquifer producing zone	13

ILLUSTRATIONS--Continued

Page

Figure 7. Hydrographs of water levels in key observation wells and Pasco Lake, with pumping and rainfall ---------- 16

8-12. Maps showing:

8. Average water table in the surficial aquifer, September 1976 to May 1977 ---------- 18

9. Average potentiometric surface of the Upper Floridan aquifer, September 1976 to May 1977 ---------- 19

10. Average water table in the surficial aquifer, September 1980 to May 1981 ---------- 20

11. Average potentiometric surface of the Upper Floridan aquifer, September 1980 to May 1981 ---------- 21

12. Location of the hydrologic anomaly and Pleistocene terraces ---------- 22

13. Hydrographs showing relations between lake stage and ground-water levels, rainfall, and pumping, 1977-82 -------- 25

14. Graph showing concentrations of dissolved solids in water from the producing zone ---------- 29

15. Diagram showing conceptual model of the hydrogeologic system ---------- 31

16-27. Maps showing:

16. Model-simulated water table in the surficial aquifer for predevelopment conditions ---------- 36

17. Model-simulated potentiometric surface of the Upper Floridan aquifer for predevelopment conditions -------- 37

18. Model-simulated drawdown in the water table in the surficial aquifer, resulting from regional pumping adjacent to the Cross Bar Ranch well field ---------- 38

19. Model-simulated drawdown in the potentiometric surface of the Upper Floridan aquifer, resulting from regional pumping adjacent to the Cross Bar Ranch well field ---------- 39

20. Model-simulated water table in the surficial aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day ---------- 42

21. Model-simulated potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day ---------- 43

22. Model-simulated drawdown in the water table in the surficial aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day ---------- 44

23. Model-simulated drawdown in the potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day --- 45

ILLUSTRATIONS--Continued

Page

Figures 16-27. Maps showing--continued:

24. Model-simulated water table in the surficial aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day ---------- 46

25. Model-simulated potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day ----- 47

26. Model-simulated drawdown in the water table in the surficial aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day ----- 48

27. Model-simulated drawdown in the potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day ---------- 49

28. Diagram showing modeling procedures ---------- 56

29-34. Maps showing:

29. Model grid encompassing the Cross Bar Ranch well field ---------- 57

30. Cross Bar Ranch model grid and its relation to the regional well-fields area model grid ---------- 59

31. Transmissivity of the Upper Floridan aquifer -------- 66

32. Leakance of the upper confining unit ---------- 67

33. Leakage rates through the upper confining unit for predevelopment conditions ---------- 68

34. ET-runoff from the water table in the surficial aquifer for predevelopment conditions ---------- 70

35. Graph showing effects of varying ET-runoff and recharge parameters ---------- 76

36. Graph showing effects of varying boundary flow and hydraulic parameters ---------- 77

TABLES

Page

Table 1. Hydrogeologic framework ---------- 8

2. Well construction characteristics ---------- 9

3. Effects of acidization on specific capacity of production wells ---------- 14

4. Chemical analyses of ground water in the well field ---------- 27

TABLES--Continued

Page

Table 5. Summary of water-balance and water-level data simulated by the model under varying conditions of pumping ---------- 34

6. Values for hydrologic parameters of the calibrated steady-state model ---------- 64

7. Observed and simulated water levels for model calibration and validation ---------- 72

8. Statistics of model calibration ---------- 73

9. Statistics of model validation ---------- 74

10. Range in head fluctuations resulting from model-sensitivity tests ---------- 78

ABBREVIATIONS AND CONVERSION FACTORS

Factors for converting inch-pound units to International System of Units (SI) and abbreviation of units

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.09294	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
gallon per minute (gal/min)	0.00006309	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
square feet per day (ft^2/d)	0.09290	square meters per day (m^2/d)
feet per day per foot [(ft/d)/ft]	1.0	meters per day per meter [(m/d)/m]
inches per year (in/yr)	25.4	millimeters per year (mm/yr)

HYDROGEOLOGY OF THE CROSS BAR RANCH WELL-FIELD AREA AND PROJECTED IMPACT OF PUMPING, PASCO COUNTY, FLORIDA

By C. B. Hutchinson

ABSTRACT

The Cross Bar Ranch well field, occupying 13 square miles in central Pasco County, contains 17 wells that tap the upper 600 feet of the Upper Floridan aquifer. The well field is permitted for an average annual withdrawal of 30 million gallons per day and a maximum daily withdrawal of 45 million gallons. Digital models of steady-state ground-water flow were used to assess the environmental impact of pumping such large quantities of water from an area where aquifers were not previously developed. Aquifers of interest include the surficial aquifer, consisting of a thin bed of fine sand, and the Upper Floridan aquifer, which comprises a 900-foot thick sequence of highly transmissive carbonate rocks.

Regional pumping near the Cross Bar Ranch well field causes drawdowns to be greatest in the southern part of the well field. At the southern boundary of the well field, the model-simulated water-table declines in the surficial aquifer and potentiometric surface of the Upper Floridan aquifer are 0.6 foot and 1 foot, respectively. These drawdowns primarily result from pumping 30 million gallons per day from the Cypress Creek well field, about 5 miles southeast of Cross Bar Ranch.

Pumping from the Cross Bar Ranch well field was simulated to assess the extent and depth of cones of depression around the well field. At the average annual permitted rate of 30 million gallons per day, a cone 5 to 17 feet deep in the water table spread over an 8-square-mile area and a cone 5 to 21 feet deep in the potentiometric surface spread over a 15-square-mile area. Under the 45-million-gallon-per-day maximum permitted rate, simulated drawdown was 5 to 26 feet in the water table of the surficial aquifer and 5 to 35 feet in the potentiometric surface of the Upper Floridan aquifer over areas of 16 and 28 square miles, respectively. The surficial aquifer could possibly be completely dewatered in small areas in the northern part of the well field when the Upper Floridan aquifer is pumped at the maximum rate. Pumping increases downward leakage from tne surficial aquifer to the Upper Floridan aquifer and, ultimately, results in reduced evapotranspiration and surface runoff.

INTRODUCTION

The Cross Bar Ranch well field occupies 13 mi^2 in north-central Pasco County (fig. 1). Seventeen wells that average 688 feet in depth have been permitted for an average annual withdrawal of 30 Mgal/d and a maximum daily withdrawal of 45 Mgal. In addition to this pumpage, water levels in the well-field area are affected by pumping elsewhere in the region for irrigation and public supplies.

The well field supplies water to Pinellas and western Pasco Counties. Production started in April 1980 and averaged about 12 Mgal/d through 1982. The potential impact on the hydrologic system of pumping large quantities of water from an area where aquifers were not previously developed is of concern to water managers and nearby landowners. Even at reduced levels of pumping, concern has been raised over the declining level of Pasco Lake and interfering cones of depression around the Cross Bar Ranch and Cypress Creek well fields.

Purpose and Scope

The purpose of this study is to evaluate the long-term availability of the ground-water supply in the Cross Bar Ranch area by focusing on the following:

1. Describe the hydrogeologic framework;
2. Provide a quantitative description of the ground-water flow system; and
3. Project the impact of pumping.

The investigation includes compilation of data from about 50 monitor wells, test wells, and production wells within a 121-mi^2 study area, including the 13-mi^2 well field. Hydrologic and geologic records examined and analyzed include rainfall, streamflow, lake levels, ground-water levels, aquifer-test data, and geologic data, including geophysical logs and drillers' logs. Two aquifers were delineated and maps were prepared that show general hydrologic conditions within each aquifer. The data were used to develop a digital model of the ground-water system.

This report is organized to focus on the project objectives listed above. The policy for most U.S. Geological Survey reports that deal with model development is to discuss modeling procedures in detail. Generally, this entails describing the grid system, boundary conditions, input data, calibration and validation procedures, and model sensitivity. Some reports even provide listings of the model-input data and FORTRAN coding changes that were made to modify a standard model. This information can be used by hydrologists and engineers to evaluate the technical quality of a study, but it is generally overlooked by water managers and public officials. To broaden audience appeal and focus on project objectives, a discussion of modeling procedures is given in a Supplemental Data section at the end of the report.

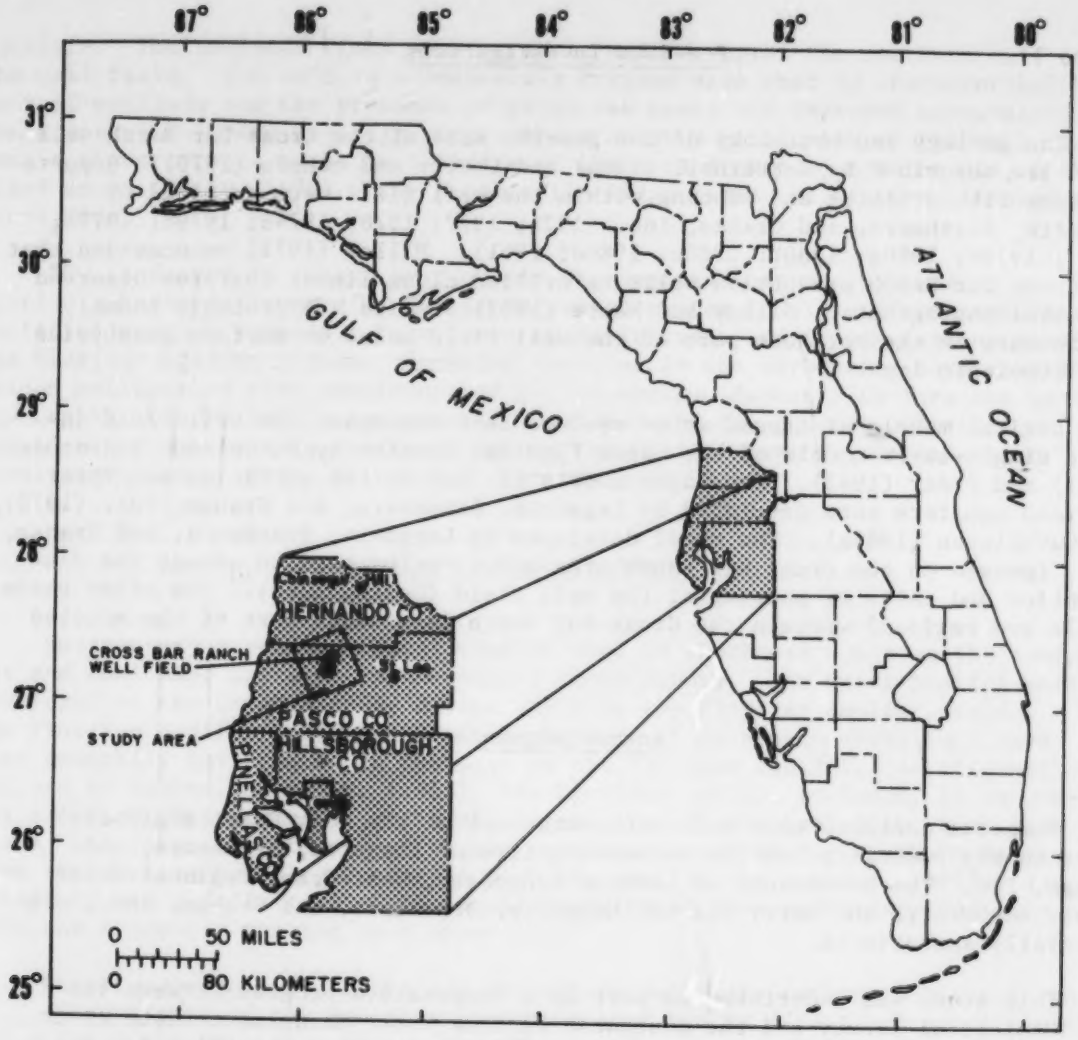

Figure 1.--Location of the Cross Bar Ranch well field and study area.

Approach

The hydrogeologic framework is defined through analysis of well logs, aquifer tests, water-level measurements, and water-quality data. Quantitative estimates of flow to and from the ground-water system are made by developing a conceptual model that couples the hydrogeologic framework with the hydrologic cycle. The flow estimates are verified and refined using a digital model that simulates ground-water levels and flow in two layers. Modeling results serve as a basis for evaluating the impact of well-field development.

Previous Investigations

The geology and hydrology of the general area of the Cross Bar Ranch well field are described by Wetterhall (1964) and Cherry and others (1970). Reports that describe drilling and testing within the well field were prepared by Leggette, Brashears, and Graham, Inc. (1976; 1977; 1978; 1979a; 1979b; 1979c; 1979d; 1979e; 1980a; 1980b; 1980c; 1980d; 1981). Miller (1977) recommended that the Cross Bar Ranch production wells be drilled along linear features observed on aerial photographs. Gilboy and Moore (1982) studied a hydrologic anomaly that occurs in the northern part of the well field based on surface geophysics and lithologic logs.

Digital models of ground-water systems that encompass the well field include single-layer models of the Upper Floridan aquifer by Hutchinson and others (1981) and Ryder (1982). Two-layer models of flow in the surficial and Upper Floridan aquifers were developed by Leggette, Brashears, and Graham, Inc. (1978), and Hutchinson (1984a). The model developed by Leggette, Brashears, and Graham, Inc., focused on the Cross Bar Ranch area and is being used to manage the distribution and rates of pumping at the well field (Heath, 1983). The other three models are regional wherein the Cross Bar Ranch is a small part of the modeled area.

Acknowledgments

Numerous contacts were made with personnel of the West Coast Regional Water Supply Authority and the consulting firm of Leggette, Brashears, and Graham, Inc. The assistance of Loretta Hennessey, West Coast Regional Water Supply Authority, and Harry Oleson, Leggette, Brashears, and Graham, Inc., are especially appreciated.

This study was undertaken as part of a cooperative program between the U.S. Geological Survey and the Southwest Florida Water Management District to evaluate the hydrogeology of the aquifer system underlying the Cross Bar Ranch well field. Knowledge gained through this assessment will help evaluate the environmental impact caused by pumping from the Cross Bar Ranch well field.

HYDROGEOLOGIC FRAMEWORK

Physical Setting

The study area occupies 121 mi^2 (fig. 2). Four physiographic units in or near the well field have been identified from areal photography and topographic maps (Gilboy and Moore, 1982; Hutchinson, 1984a). The Lakes Terrace physiographic unit that occupies the southern half of the well field is a wetlands area characterized by numerous lakes and sinkholes. The Central Swamp physiographic unit, about 5 miles southeast of the well field, is characterized by marshy areas that are maintained by upwelling of artesian water from underlying

aquifers. The Lowlands Plain physiographic unit occupies the northern half of the well field. The unit is a moderately drained area that is characterized by lack of wetlands and the presence of large oak trees and improved pastureland. The Brooksville Ridge physiographic unit is about 3 miles east of the well field and is characterized by thick deposits of white sand that seem to be old, stabilized dunes (White, 1970). The Brooksville Ridge forms the eastern limit of the study area

The landscape is dotted by sinkhole depressions that are typical of Florida's karst environment. The ground-water system consists of an unconfined surficial aquifer underlain by a leaky confining unit and deeper carbonates of the Floridan aquifer system. Solution cavities in the carbonates have caused sudden collapse or slow subsidence of the overburden deposits to form the karst topography. Water levels are near land surface and the general direction of ground-water movement is northwest toward the Gulf of Mexico. Ground-water levels have been lowered by pumping from the well field.

Aquifers and Confining Units

Sedimentary deposits several hundred feet in thickness comprise the aquifer and confining units in north-central Pasco County. The water-bearing unit developed at the Cross Bar Ranch well field is the Floridan aquifer system. The Floridan aquifer system is a thick sequence of carbonate rocks that have been generally referred to in the past as the Floridan aquifer. As originally defined by Parker and others (1955), the Floridan aquifer included, in ascending order, highly permeable rocks of all or parts of the Lake City, Avon Park, Ocala, and Tampa Limestones and highly permeable parts of the Hawthorn Formation that are in hydrologic contact with the rest of the aquifer. Miller (in press) in his redefinition of the aquifer indicated that subsurface information and hydraulic testing have shown that:

1. Except very locally, there are no high-permeability carbonate rocks in the lower part of the Hawthorn Formation that are in direct hydraulic contact with the main part of the Floridan aquifer system.
2. The Lake City Limestone cannot be distinguished lithologically or faunally from the overlying Avon Park Limestone and should be part of the Avon Park.
3. The Avon Park is more properly called a "formation" rather than a "limestone" because the unit contains rock types other than limestone.
4. Regionally, permeable carbonate rocks extend to deeper stratigraphic horizons than those included in the Floridan aquifer as it was originally described by Parker and others.

Miller's work represents one phase of a U.S. Geological Survey program, termed Regional Aquifer Systems Analysis (RASA), to study Tertiary limestone aquifers in Florida and parts of Georgia, Alabama, and South Carolina. Subsequent phases of the RASA study have been based on the hydrogeologic framework described by Miller. The Floridan aquifer system as defined by Miller (in press) comprises:

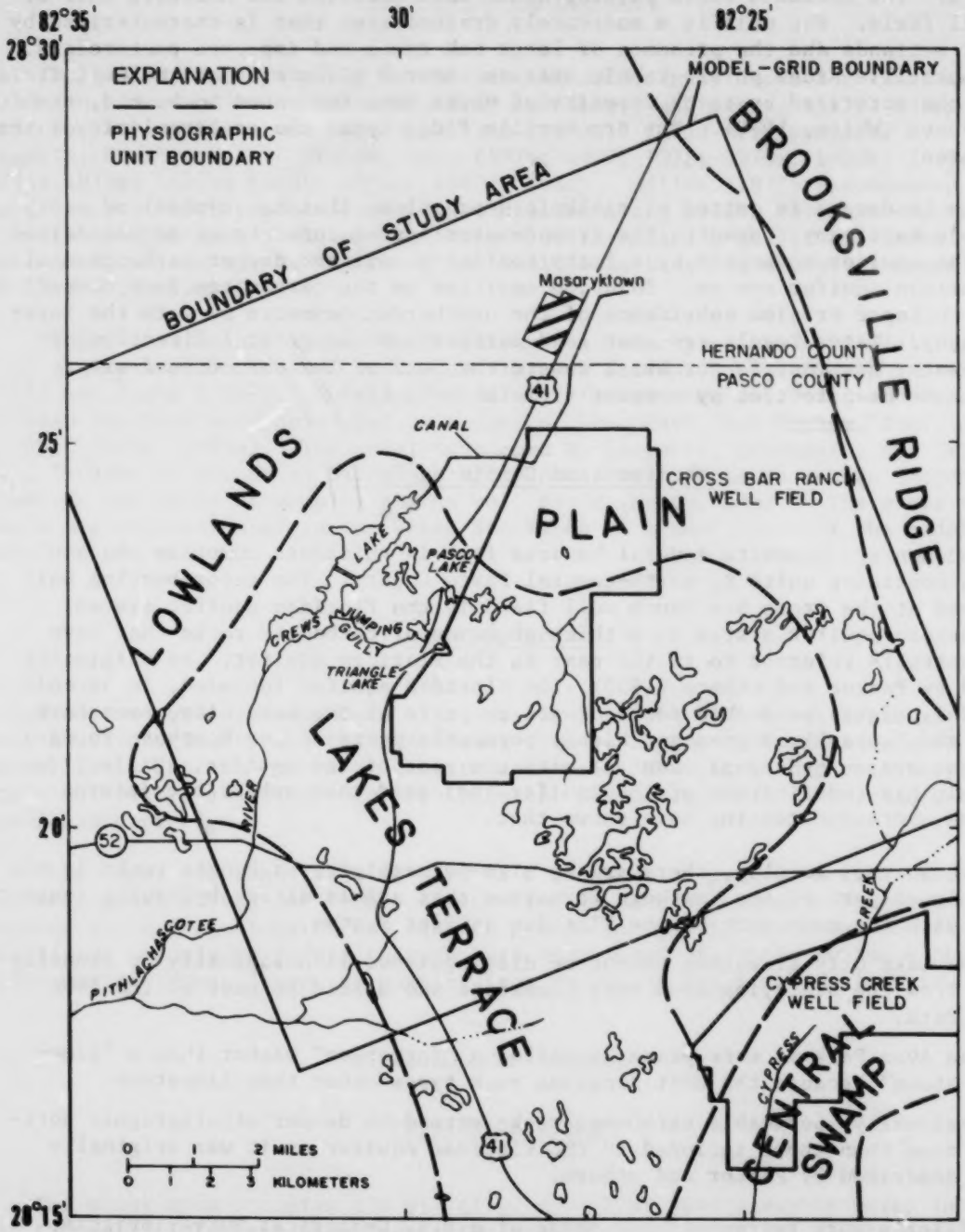

Figure 2.--Physiography of the well-field area.

"a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of middle and late Tertiary age, that are hydraulically connected in varying degrees, and whose permeability is, in general, an order to several orders of magnitude greater than that of those rocks that bound the system above and below."

"... (in west-central Florida), less-permeable carbonate units of subregional extent separate the system into two aquifers, herein called the Upper and Lower Floridan aquifers."

In Pasco County, the freshwater-bearing part of the Floridan aquifer system is the Upper Floridan aquifer.

Hydrogeologic units in the Cross Bar Ranch well-field area are listed in table 1. The surficial aquifer generally is about 35 feet thick and is composed of fine-grained sand. It grades downward to a discontinuous bed of sandy clay that is about 10 to 20 feet thick and forms the upper confining unit of the Upper Floridan aquifer. The Upper Floridan aquifer is a 900-foot-thick sequence of limestone and dolomite. The underlying middle confining unit, within the Avon Park Formation, consists of low-permeability gypsiferous dolomite and dolomitic limestone. The top of the middle confining unit lies between 890 and 910 feet below sea level at observation well B-1 (Leggette, Brashears, and Graham, Inc., 1979e). Table 2 lists well-construction information for wells pertinent to the study. Figure 3 shows the locations of all production wells and key test wells in and around the well field. Figure 4 is a generalized north-south hydrogeologic section that shows aquifer relations and zones that are tapped by production wells.

Hydraulic Characteristics

Hydraulic characteristics of the aquifers and confining units were determined from laboratory tests and aquifer tests. The hydraulic conductivity of the surficial aquifer is estimated to be 10 ft/d based on laboratory measurements of core samples in nearby Hillsborough County (Sinclair, 1974). Based on this estimate, the 35-foot thick, fully saturated areas of the surficial aquifer would have a transmissivity of 350 ft^2/d. The aquifer is pumped only through shallow domestic and stock-watering wells that generally yield less than 20 gal/min.

Leakance of the upper confining unit and transmissivity of the Upper Floridan aquifer were determined by Leggette, Brashears, and Graham, Inc. (1978), from aquifer tests in the northern, central, and southern parts of the well field (fig. 5). Leakance ranges from about 0.0005 to 0.003 (ft/d)/ft and is ascribed primarily to the upper confining unit. The transmissivity at test site C is about 115,000 ft^2/d, or more than double that of the other two sites.

A comparison of specific capacities in similarly constructed and developed wells can give some indication of the variation in aquifer characteristics. Specific capacity tests indicate that the transmissivity of the Upper Floridan aquifer and the degree of well development vary widely within the well field

Table 1.--Hydrogeologic framework

Series	Stratigraphic unit	Hydrogeologic unit[1/]	Approximate thickness (feet)	Hydrogeologic characteristics
Holocene Pleistocene Pliocene	Surficial sand and clay	Surficial aquifer	35	Marine and nonmarine unconsolidated quartz sand, clay, and shells. Wells yield less than 20 gal/min. Excellent water quality. Unit is cased off in production wells.
Miocene	Hawthorn Formation	Upper confining unit	10-20	Clay with traces of sand and silt. Retards downward movement of water from the surficial to Upper Floridan aquifer.
	Tampa Limestone			
		Upper Floridan aquifer	900	Limestone and dolomite. Production wells yield up to 3,000 gal/min. Water quality is good. Upper 600 feet is tapped by production wells. Water levels are affected by regional pumping for irrigation and municipal supply.
Oligocene	Suwannee Limestone			
Eocene	Ocala Limestone			
	Avon Park Formation[1/]			
		Middle confining unit	300	Limestone and dolomite with intergranular gypsum and anhydrite. Extremely low permeability. Water quality is poor.

[1/] Based on nomenclature defined by Miller (in press).

(fig. 6). The specific capacities of 15 production wells and 1 test well (B-1), all 15 to 17.5 inches in diameter and approximately 700 feet deep, ranged from 110 to 800 gal/min per foot of drawdown. Production wells CB-7 and CB-16 are less than 700 feet deep (table 2), but their specific capacities also are within this range. Ignoring well losses, transmissivity is estimated to be directly proportional to specific capacity. Specific capacity, and hence aquifer transmissivity, is generally highest in the center of the northeast part of the well field and lowest in the northwest part.

Table 2.--Well construction characteristics

Production wells[1/]

Location	Well	Depth (feet)	Diameter (inches)		Casing depth (feet)
			Casing	Open hole	
282123082274401	CB-1	710	24	17.5	150
282133082275301	CB-2	702	24	15	158
282142082283701	CB-3	700	24	15	152
282154082280101	CB-4	705	24	17.5	155
282222082280701	CB-5	705	24	15	152
282233082283801	CB-6	705	24	17.5	155
282246082281601	CB-7	485	24	15	154
282310082281901	CB-8	710	24	17.5	151
282324082281901	CB-9	703	24	15	154
282342082274801	CB-10	710	24	17.5	152
282346082271201	CB-11	702	24	15	155
282352082263901	CB-12	710	24	17.5	120
282410082271301	CB-13	700	24	15	152
282422082263901	CB-14	710	24	17.5	120
282422082275101	CB-15	710	24	17.5	160
282442082273201	CB-16A	630	24	17.5	118
282443082263901	CB-17	710	24	17.5	117

Observation wells

Location	Well		Depth (feet)	Diameter (inches)	Casing depth (feet)	Aquifer[2/]
282851082271601	W-708		340	8	80	UF
282540082275702	Masaryktown	S	19	1.25	9	SA
282540082275701		D	82	6	29	UF
282505082271102	NRW	S	21	6	17	SA
282505082271101		D	706	6	155	UF
282326082285202	WRW	S	21	6	19	SA
282326082285201		D	642	6	153	UF
282411082261402	NERW	S	27	6	23	SA
282411082261402		D	700	6	146	UF
282259082282802	B-1	S	23	6	19	SA
282259082282801		D	701	12	143	UF
282259082282803	4-inch		1,260	4	1,235	MCU
282207082271102	SERW	S	21	6	18	SA
282207082271101		D	700	6	155	UF
281931082284102	SRW	S	13	6	9	SA
281931082284101		D	700	6	146	UF
281918082264602	Gowers	S	7	1.25	6	SA
	Corner	D	73	6	38	UF
25,T25S,R18E[3/]	W-12346		250			UF

[1/] All production wells tap the Upper Floridan aquifer.

[2/] SA = surficial aquifer; UF = Upper Floridan aquifer; MCU = middle confining unit.

[3/] Section, township, range given on Florida Bureau of Geology computer printout of lithologic log.

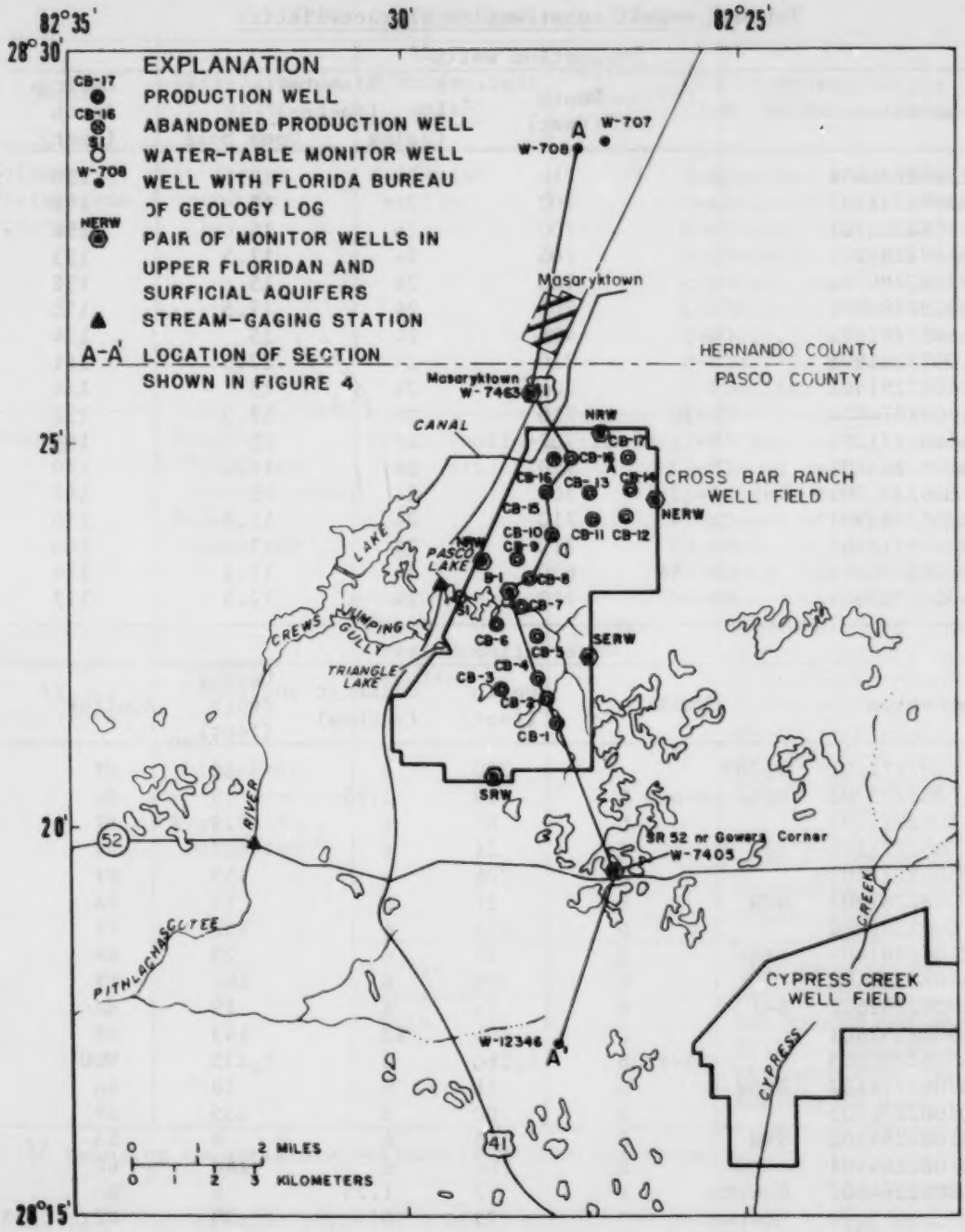

Figure 3.--Locations of data-collection sites.

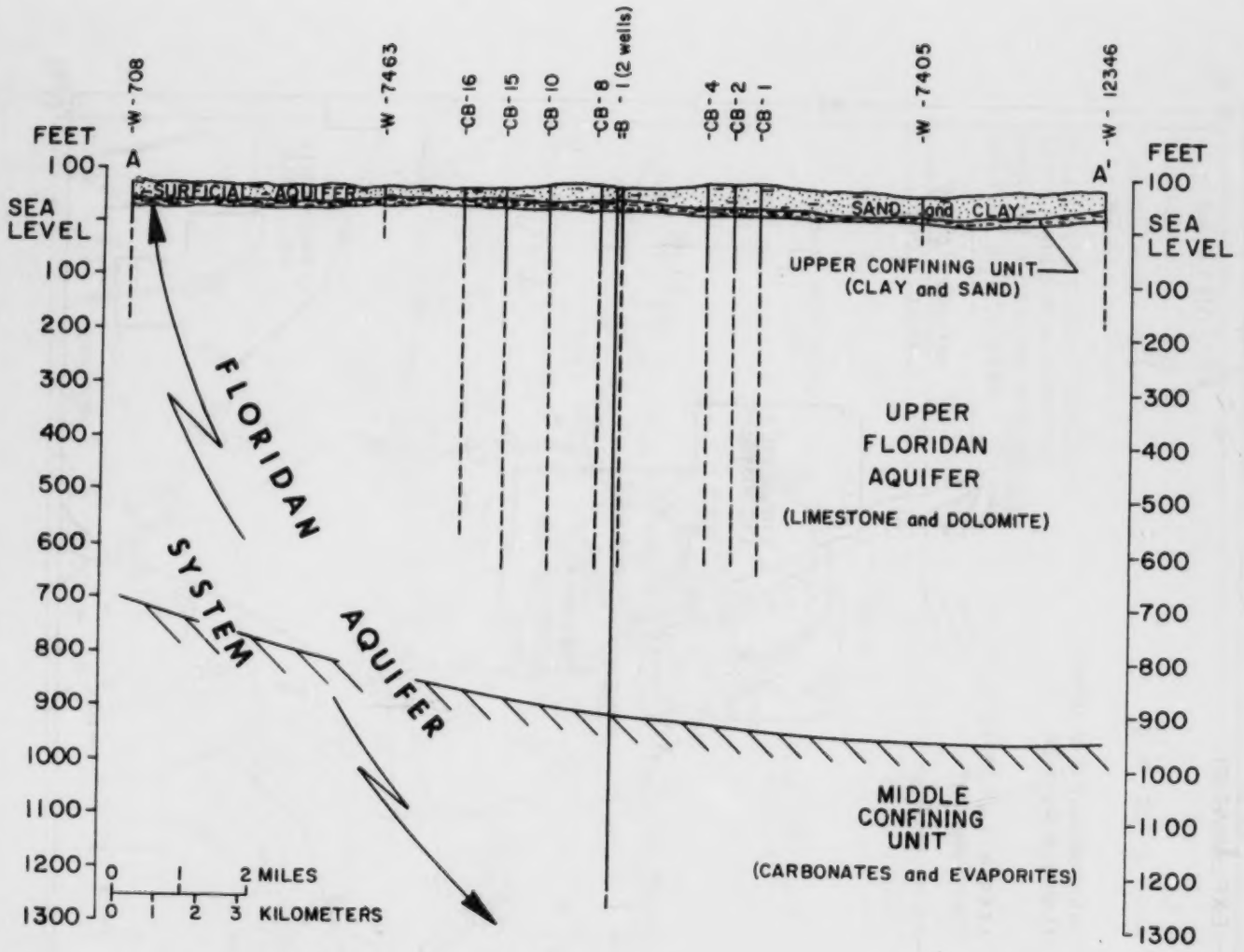

Figure 4.--Hydrogeologic section. (Location of section is shown in figure 3.)

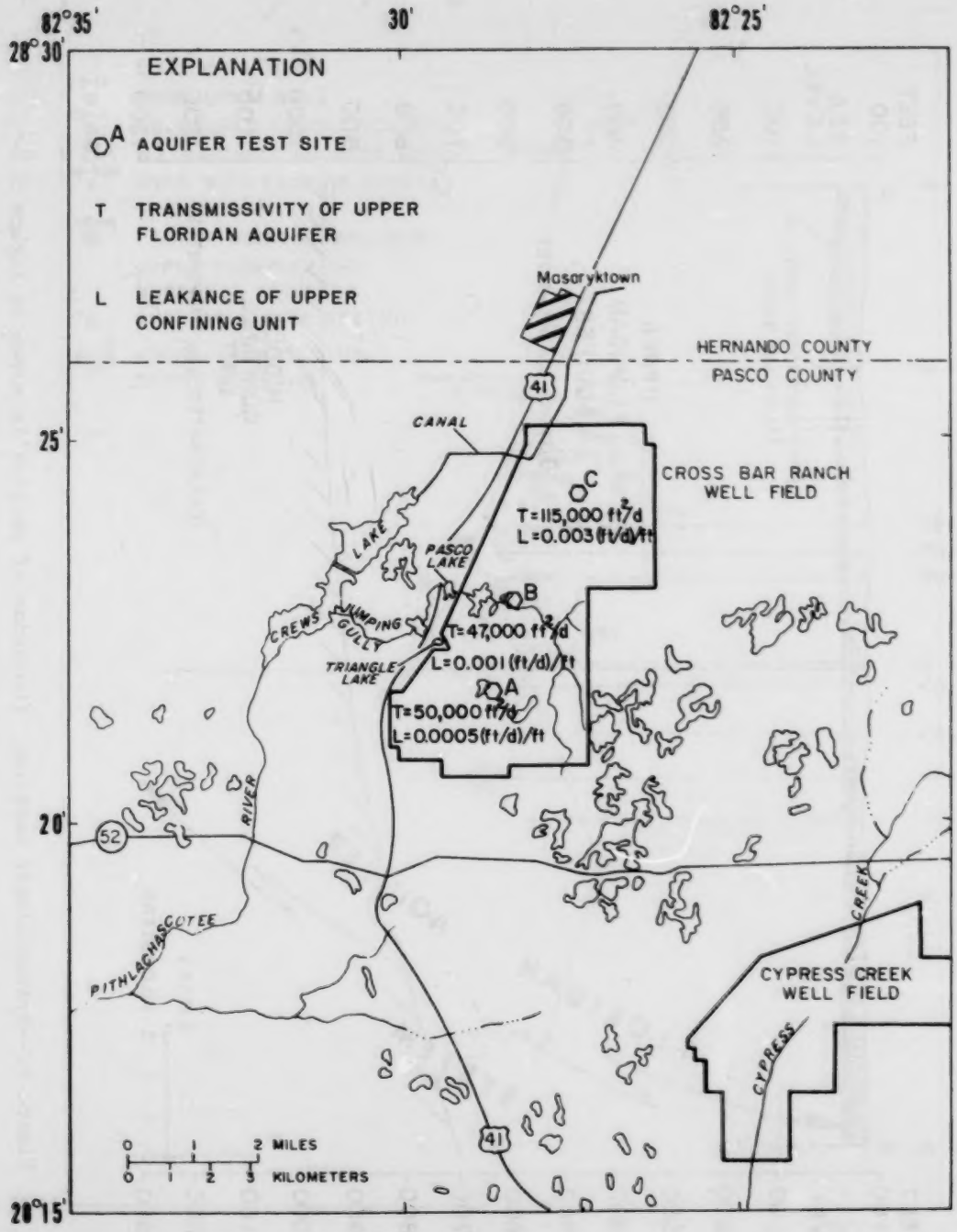

Figure 5.--Pumping test sites and values of transmissivity and leakance. (Based on tests described in Leggette, Brashears, and Graham, Inc., 1978.)

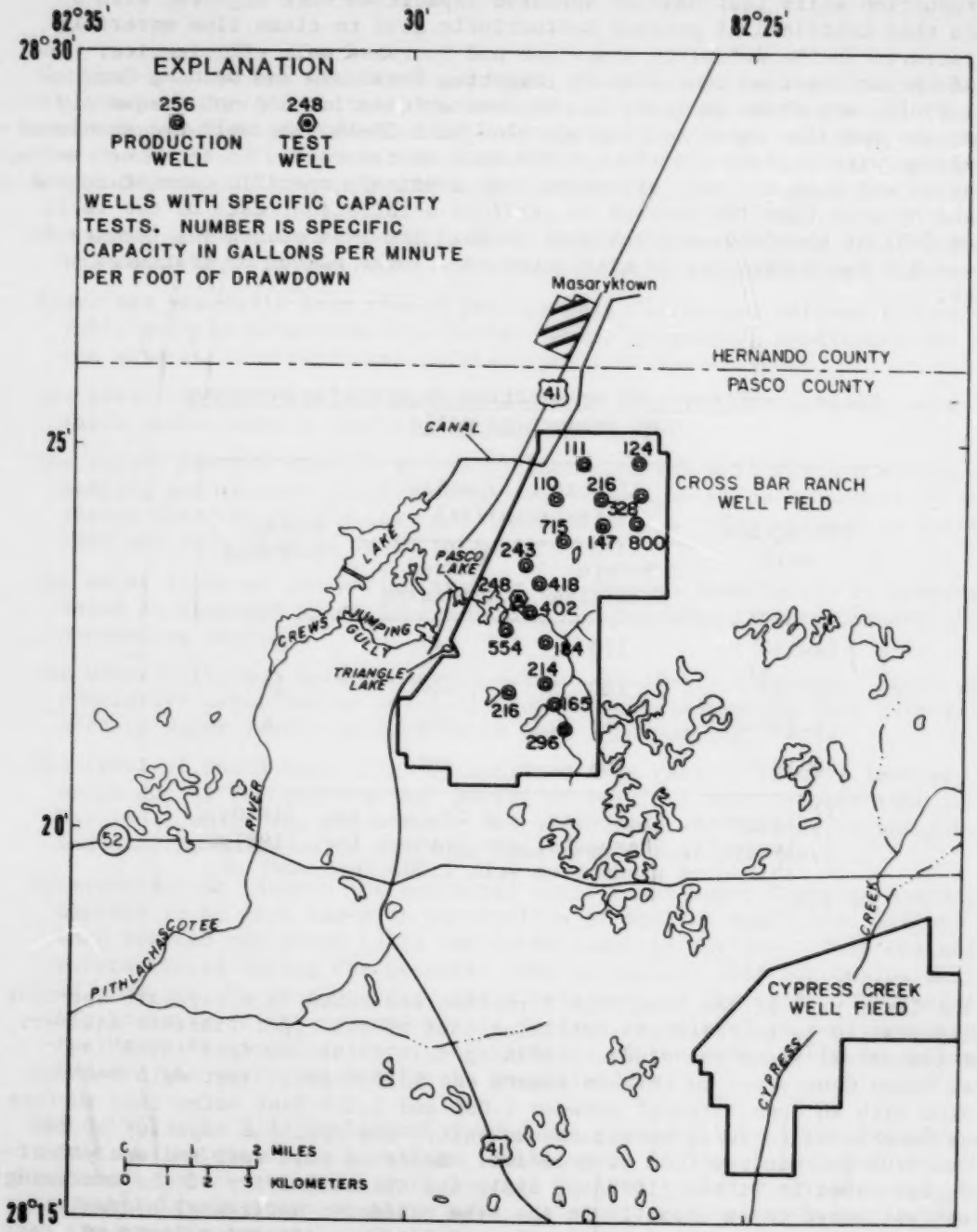

Figure 6.--Specific capacities of wells tapping the Upper Floridan aquifer producing zone.

Production wells that had low specific capacities were injected with a solution that contained 15 percent hydrochloric acid to clean fine materials from fractures in the dolomitic limestone and increase well efficiencies. Results of the acidization conducted by Leggette, Brashears and Graham, Inc. (1980a; 1981), are shown in table 3. Because acidization did not adequately increase the specific capacity of production well CB-16, the well was abandoned and replaced with well CB-16A about 1,000 feet to the east. In the other wells, acidization was also not very effective. By contrast, specific capacities had increased by more than 100 percent in previous acidization tests of two wells (C-7 and C-8) at the Cypress Creek well field. The less successful results in the Cross Bar Ranch area may be attributed to a lower number of fractures in the rock.

Table 3.--Effects of acidization on specific capacity of production wells

Production well	Specific capacity [(gal/min)/ft]		Percent increase
	Before acidizing	After acidizing	
CB-11[1/]	110	147	34
CB-15[2/]	100	110	10
CB-16[1,3/]	66	70	6
CB-16A[2/]	108	111	3

1/ Leggette, Brashears, and Graham, Inc. (1980a).
2/ Leggette, Brashears, and Graham, Inc. (1981).
3/ Abandoned production well 1,000 feet west of CB-16A.

The lower part of the Avon Park Formation was shown in a separate specific capacity test to be an effective confining unit of the Upper Floridan aquifer. Miller (in press) shows the middle confining unit to be 300 feet thick in central Pasco County and to thicken toward the Gulf Coast. Test well B-1 was completed with an open interval between 1,002 and 1,314 feet below land surface and was considered to fully penetrate the unit. The specific capacity of the well was 0.05 gal/min per foot of drawdown. Based on this test and analytical methods described by Walton (1970, p. 318), the transmissivity of the confining unit was estimated to be about 10 ft^2/d. The estimated horizontal hydraulic conductivity of the confining unit is about 0.03 ft/d. Assuming isotropy, the maximum value for leakance of the middle confining unit is estimated (by dividing vertical hydraulic conductivity by thickness, 0.03 ft/d ÷ 300 feet) to be 0.0001 (ft/d)/ft, or about one-fifth the minimum value for the upper confining unit.

Ground-Water Levels and Movement

Water levels in the surficial and Upper Floridan aquifers are monitored periodically at sites in and near the well field. Hydrographs of water levels for the period 1980-81 in selected wells along the boundary, well B-1, in the interior of the well field, and Pasco Lake (fig. 7) indicate several important hydrologic features of the well field, including:

1. The water table and the potentiometric surface are at higher altitudes in the south than in the north and trends generally parallel one another.
2. There was generally less than 2 feet of head difference between the water table and the potentiometric surface under nonpumping conditions and in the absence of significant rainfall prior to April 1980.
3. The potentiometric surface dropped to about 2 to 5 feet below the water table under pumping conditions after April 1980.
4. The potentiometric surface at the perimeter of the well field responds to pumping and reaches equilibrium almost immediately, as evidenced by the abrupt water-level changes that occurred when pumping stopped in December 1980 and then started again in January 1981.
5. The water table at the perimeter does not respond immediately to pumping, based on observed water levels during the December 1980 to January 1981 nonpumping period.
6. The water table and potentiometric surface generally follow the trend of cumulative departure of rainfall from normal, indicating that rainfall affects water levels as much as or more than pumping.
7. The level of Pasco Lake (fig. 3) declined at a rate of about 2 feet per month during the below-normal period of rainfall from October 1980 to May 1981, while the water table and potentiometric surface in shallow and deep boundary wells declined less than 1 foot per month.
8. Interconnection between the surficial aquifer and Upper Floridan aquifer appears to be good based on parallelism of and the small head difference between the water table and potentiometric surface. This was not substantiated during the December 1980 to January 1981 nonpumping period, however, because no water-table response was detected. The immediate response in the potentiometric surface is related to confinement of the Upper Floridan aquifer. The response of the water table is subtle because the surficial aquifer is unconfined.

Since 1971, the U.S. Geological Survey has prepared maps that show the water table and potentiometric surface in the Cross Bar Ranch area for each May and September, representing seasonal low and high water-level periods, respectively. Water levels shown on these maps are considered to represent levels at or near the troughs and peaks of annual water-level hydrographs. Of the available maps, those for September 1976 and May 1977 (Ryder and Mills, 1977a; 1977b) apparently best represent high and low water levels under prepumping conditions before development of the well field in April 1980. The water table and potentiometric surface, derived as an average of high and low annual conditions from the maps, are considered to represent prepumping average water levels for the

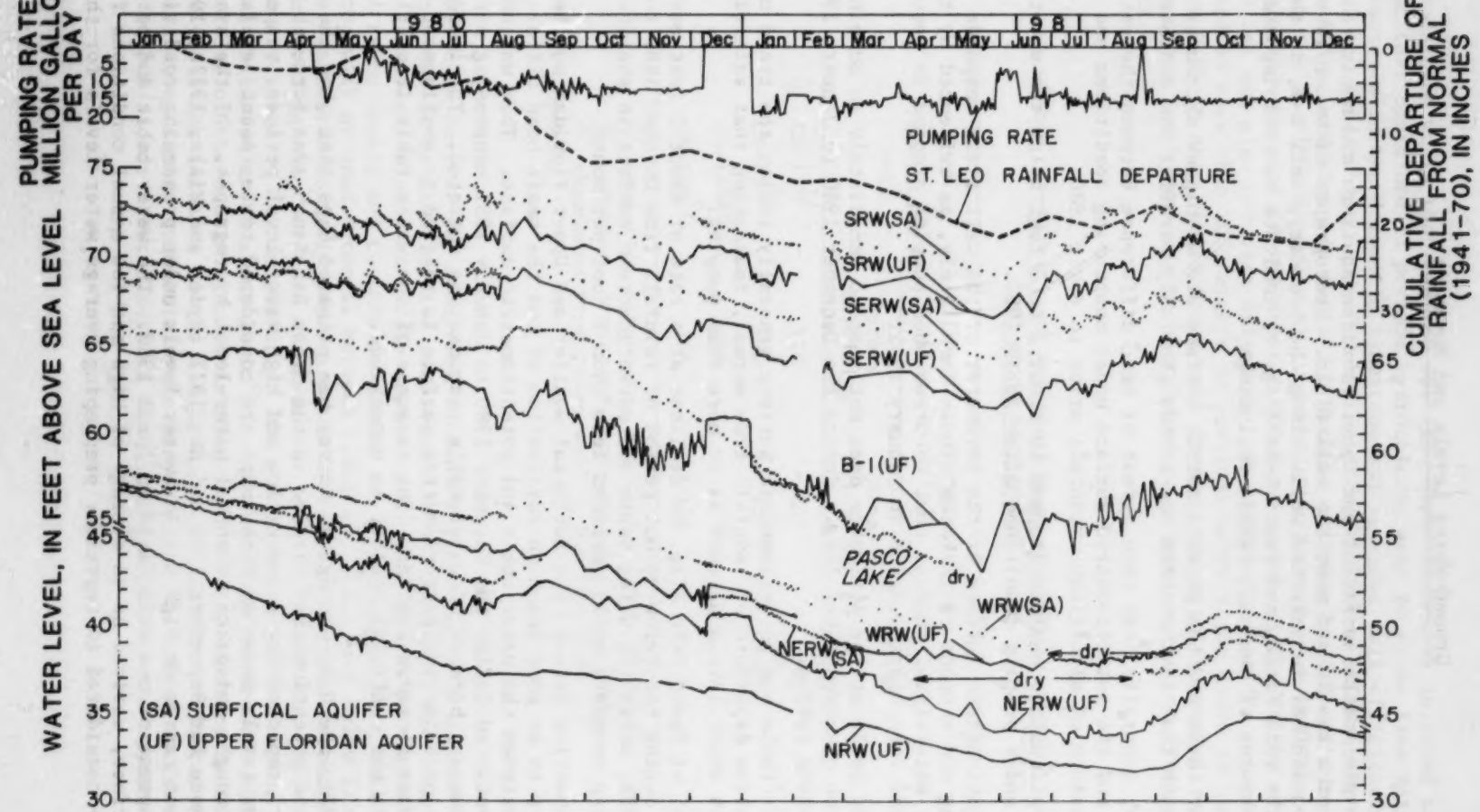

Figure 7.--Water levels in key observation wells and Pasco Lake, with pumping and rainfall.

year prior to May 1977 (figs. 8 and 9). Water levels from maps for September 1980 (Yobbi and others, 1980) and May 1981 (Yobbi and Woodham, 1981) were averaged to represent average water levels under pumping conditions (figs. 10 and 11). The average pumping rate for this period was 12.8 Mgal/d, or less than one-half the annual average permitted rate. The average water levels were used to calibrate and validate a digital model of steady-state ground-water flow.

Water in the surficial and Upper Floridan aquifers moves northwestward across the well field from an area of elevated water levels known as the "Pasco high." Under prepumping conditions, the gradient of the potentiometric surface (fig. 9) varies from about 3 ft/mi north and south of the well field to about 6 ft/mi within the well field. The changes in gradient apparently result from a "hydrologic anomaly" within the well field (Gilboy and Moore, 1982, p. 1).

Under pumping conditions, the water table (fig. 10) and potentiometric surface (fig. 11), areally, are 3 to 10 feet lower than under predevelopment conditions. The lower levels result from the combined effects of pumping and reduced recharge. Rainfall, and hence recharge, was below normal during the pumping period compared to predevelopment conditions (fig. 7).

The cone of depression in the water table in the northern part of the well field (fig. 10) is only partially related to pumping and probably indicates that the confining bed there is more leaky compared to the southern part. The cone is centered around production well CB-16A; however, this well had not been used for production because of its relatively low yield. A depression in the water table is indicated under prepumping conditions (fig. 8), but is less defined in part because few observation wells were available. More observation wells were available for defining the water table under pumping conditions.

Hydrologic Anomaly

A hydrologic anomaly occurs in the Upper Floridan aquifer in the northern part of the well field (fig. 12). The anomaly is reflected in the potentiometric surface as a steepening gradient (figs. 9 and 11). The change in gradient indicates a change in hydrogeology. Pumping test results also indicate the presence of the anomaly. During a 1979 pumping test of well N-12, very little water-level response occurred in wells NOW-1 and NOW-2 (fig. 12). During another test in 1978, well CB-13 was pumped and the response at well C-1 was about half that observed in the equidistant well C-2. During an irrigation cycle pumping of the Rovan Farms well, the drawdown in well B-2 was only 25 percent of that in well B-3. In each case, the water-level response in observation wells on the opposite side of the hydrologic anomaly from the pumped well was significantly less than expected. Based on the pumping tests, the hydrologic anomaly is placed between wells N-12 and NOW-1, CB-13 and C-1, and B-3 and B-2.

Gilboy and Moore (1982) observed that the hydrologic anomaly was almost exactly beneath the 70-foot topographic contour. The 70-foot level is suspected to represent a brief stand of sea level during the late Pliocene or early Pleistocene age, and the gently sloping flatlands on either side of the

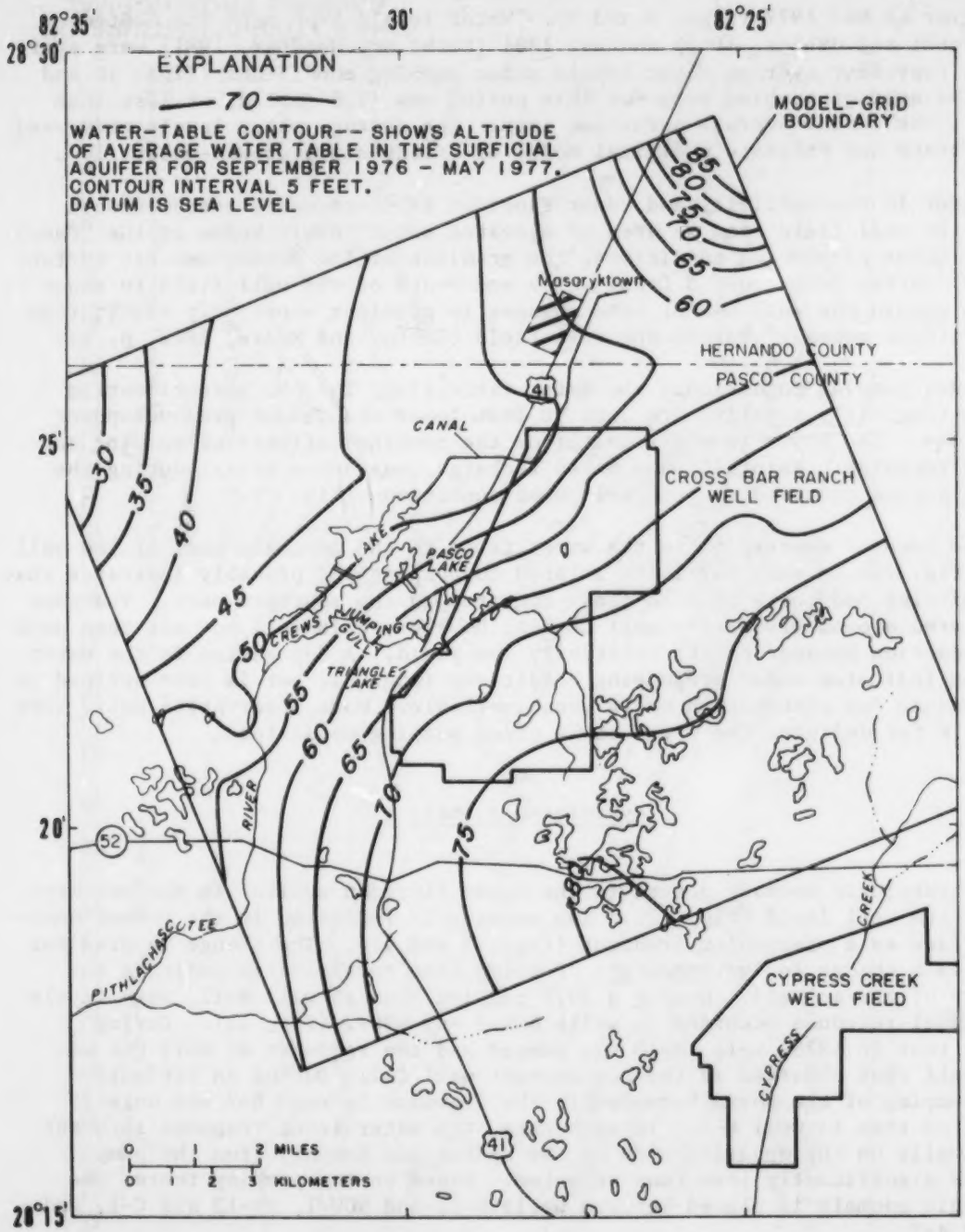

Figure 8.--Average water table in the surficial aquifer, September 1976 to May 1977.

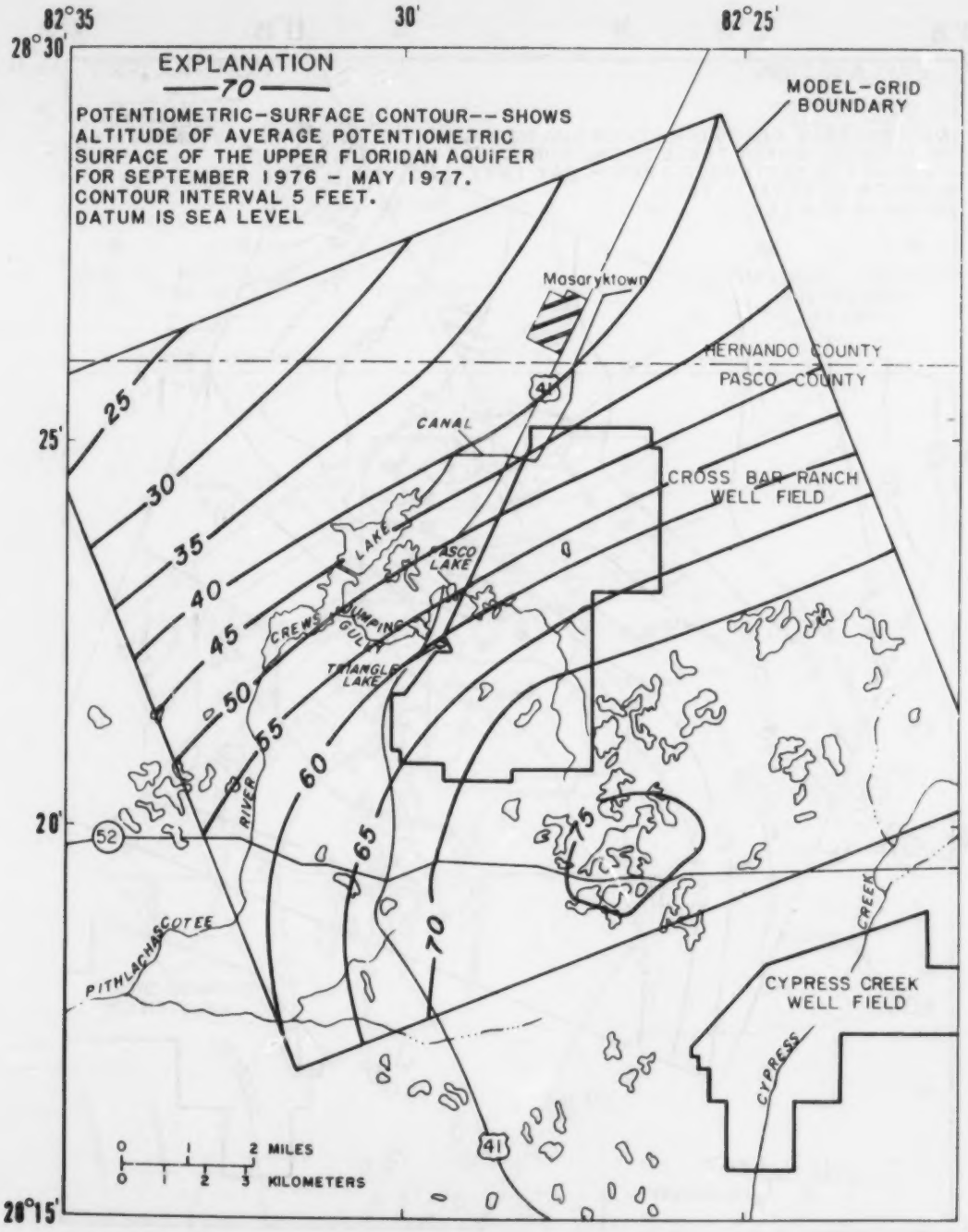

Figure 9.--Average potentiometric surface of the Upper Floridan aquifer, September 1976 to May 1977.

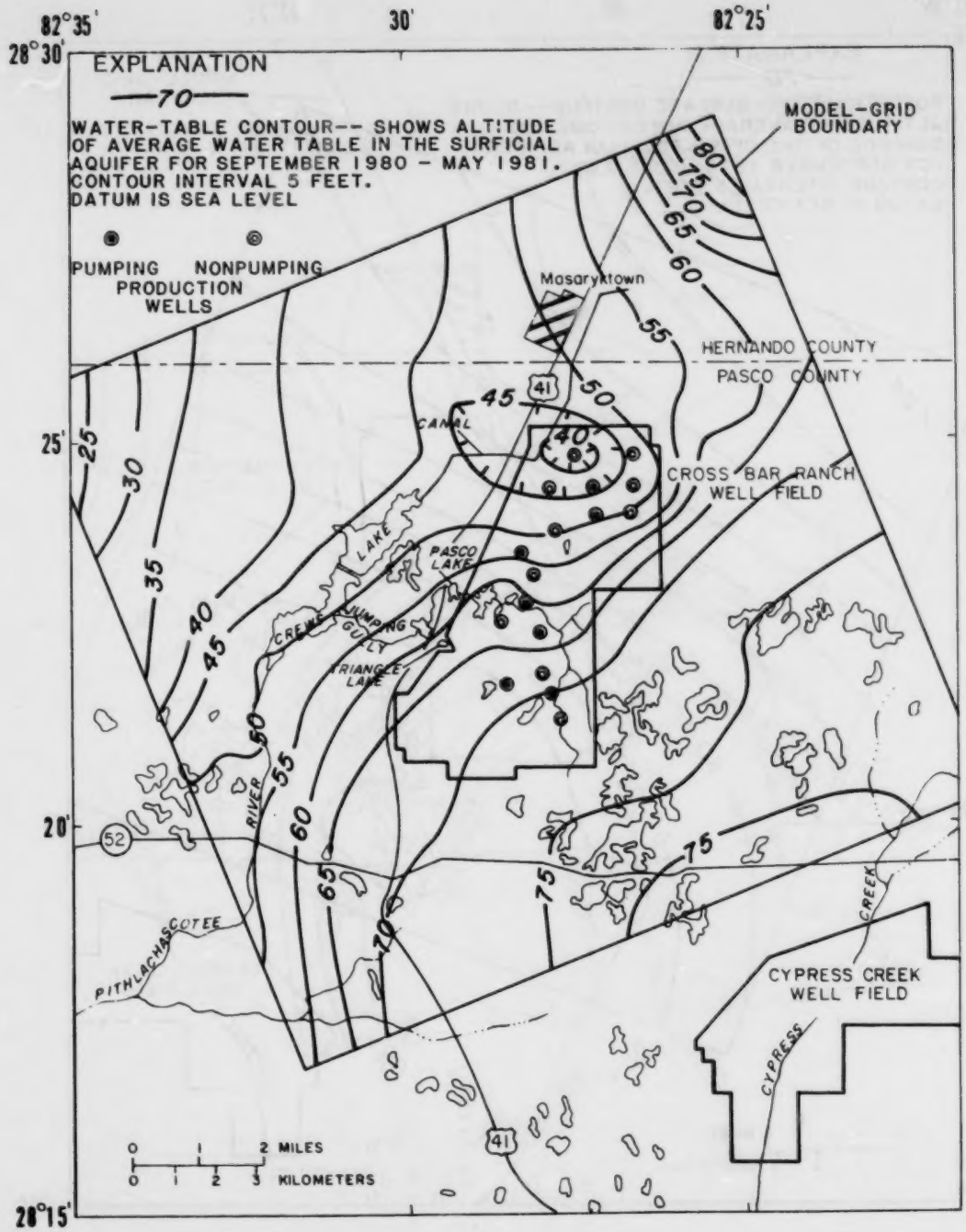

Figure 10.--Average water table in the surficial aquifer, September 1980 to May 1981.

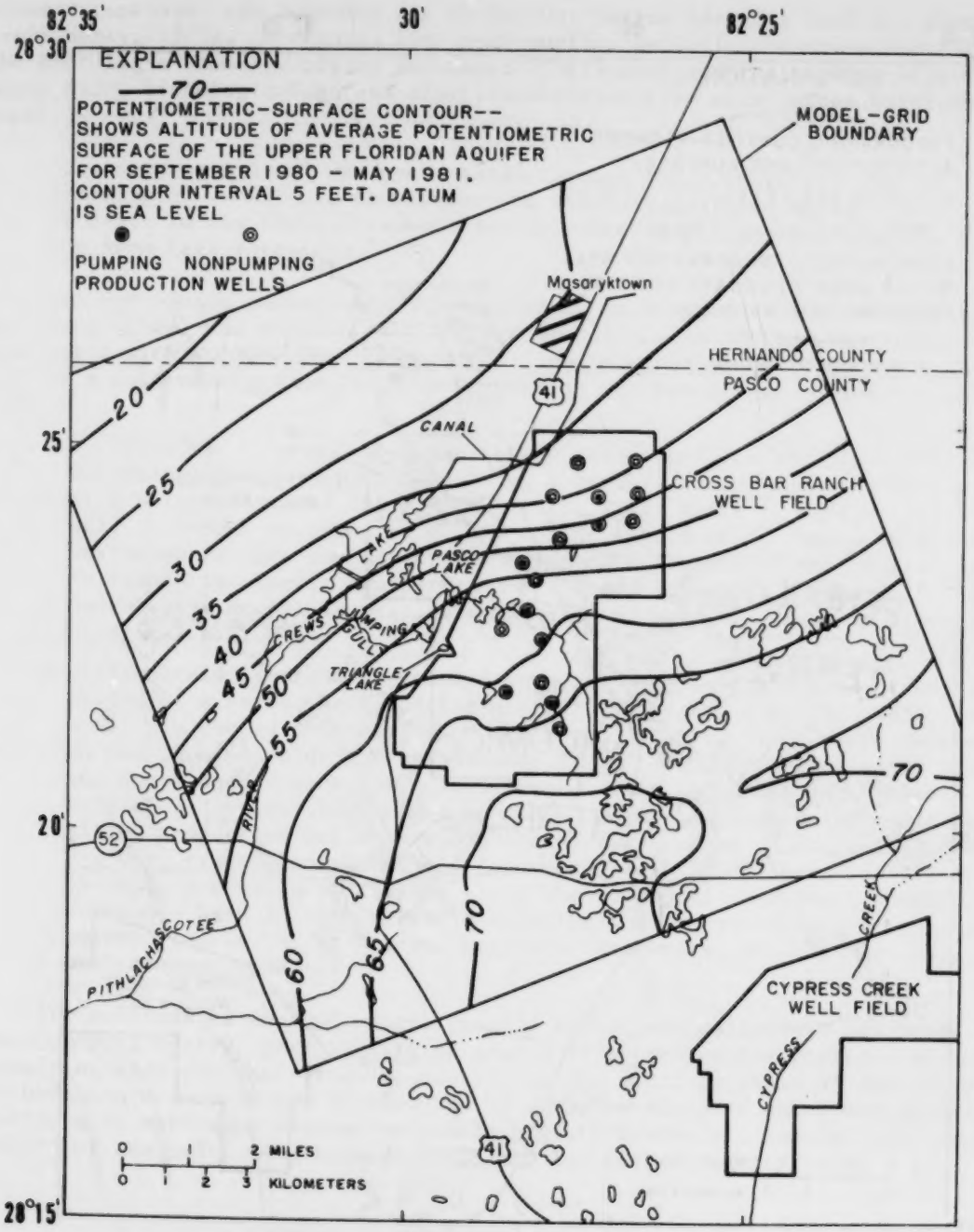

Figure 11.--Average potentiometric surface of the Upper Floridan aquifer, September 1980 to May 1981.

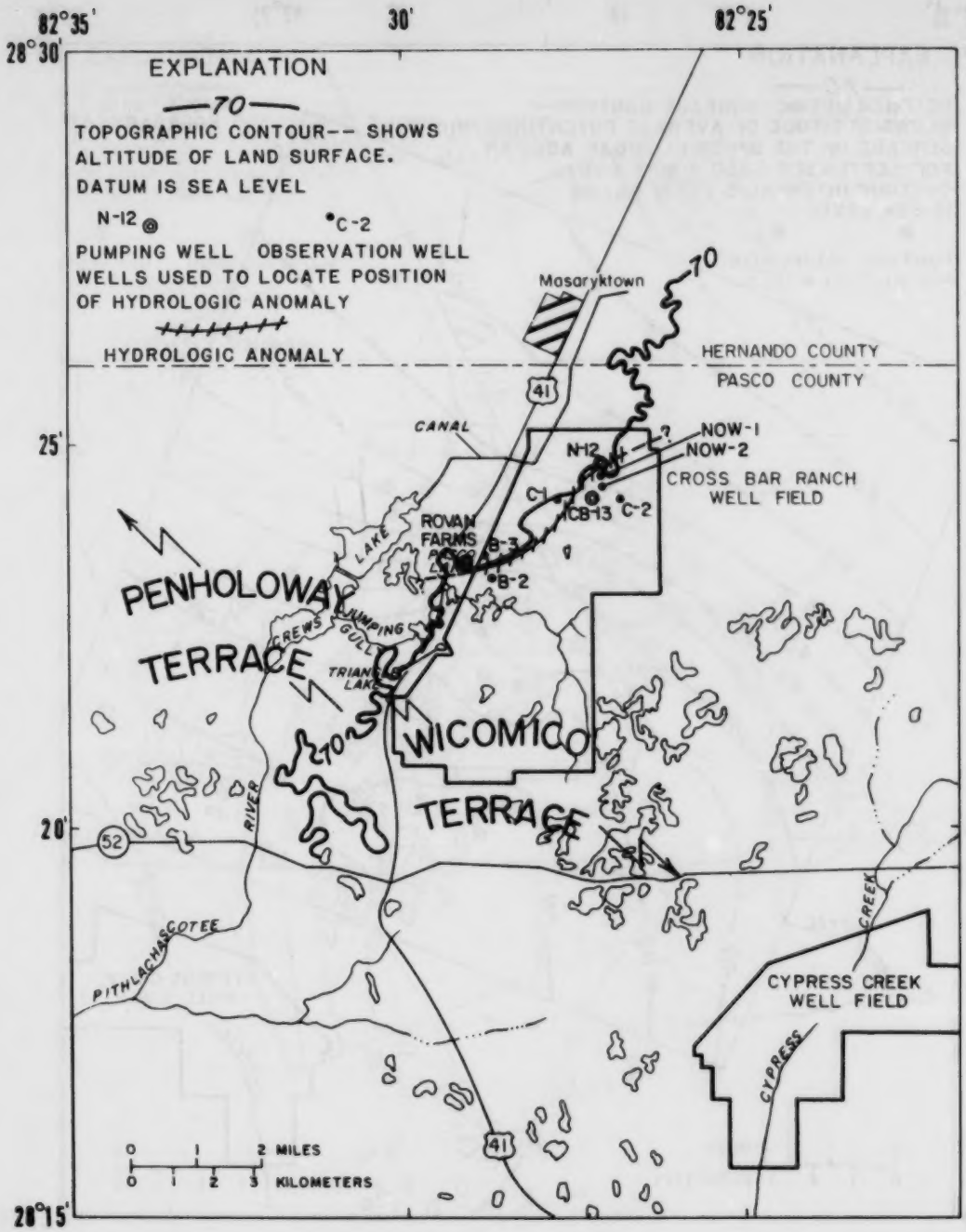

Figure 12.--Location of the hydrologic anomaly and Pleistocene terraces.

contour represent the Wicomico and Penholoway marine terraces (Alt and Brooks, 1965; Healy, 1975). Presuming that near-surface geologic structure controlled the hydrologic anomaly, Gilboy and Moore (1982) analyzed the shallow stratigraphy using lithologic logs and electrical-resistivity data. They concluded that:

> "... nothing unusual was encountered through the geophysical (and lithologic) work. ... the answer (to the hydrologic anomaly) rests at depth in the highly transmissive dolomite/limestone sequence of the Avon Park Formation."

The hydrologic anomaly might be explained by a hypothesis of Altschuler and Young (1960) who suggest that ancient shorelines in central Florida are associated with uplift. The demarcation line between the terraces may actually be a fault scarp. Faulting could explain the hydrologic anomaly in two ways.

1. Faulting could create a condition where permeable beds are displaced and butted against less permeable beds, thereby lowering the transmissivity of a narrow strip of the aquifer if the fault block is narrow. If a well is pumped on one side of the fault, little effect would be observed on the other side because of the near-vertical seal of the fault. This is common in clastic aquifers and oil-producing sands of the Gulf Coast where water or oil is trapped structurally, but not common in limestone aquifers of Florida.

2. Faulting could create a brecciated zone, thereby increasing the transmissivity of a narrow strip of the aquifer (Moore and Stewart, 1983). If a well is pumped on one side of the fault, little effect would be seen on the opposite side due to movement of large quantities of water along the fault zone toward the pumping well. This is common in limestone aquifers. Miller (1977) used fracture trace analysis as the basis for siting production wells along suspected fault zones in the well field. However, production well CB-16 (abandoned well 1,000 feet west of CB-16A), subsequently drilled along the suspected hydrologic anomaly, proved to have a lower specific capacity than those drilled at random between traces (H. F. Oleson, Leggette, Brashears, and Graham, Inc., oral commun., 1983).

The location of the hydrologic anomaly within the well field was based on local pumping tests. More testing is needed to determine the position of the anomaly outside the well-field boundary. In the modeling phase of this study, the hydrologic anomaly was represented by a narrow strip of the Upper Floridan aquifer with extremely low and extremely high transmissivities. A better calibration of the model was obtained using the low transmissivity value.

Surface Water-Ground Water Relations

The study area contains numerous streams and lakes that interact with the ground-water system. The major streams are the Pithlachascotee River, Masaryktown-Crews Lake flood-control canal, and Jumping Gully (fig. 3). Lakes of particular interest are Crews Lake, Pasco Lake, and Triangle Lake.

The Pithlachascotee River derives its flow from overland runoff, outflow from Crews Lake, and upward leakage from the Upper Floridan aquifer. Streamflow measured periodically at a gaging station at State Highway 52 from 1972 to 1981 has ranged between zero and 37 ft^3/s. The average of 64 measurements during this 10-year period is 4.5 ft^3/s, or 0.4 in/yr from the 150-mi^2 drainage area above the gage. Base flow, which represents ground water contributed to streamflow, is estimated to be about 3.1 ft^3/s, or 0.3 in/yr, based on measurements during March, April, October, and November (typically months of low rainfall and runoff).

The Masaryktown-Crews Lake canal was dug in the mid-1960's to divert floodwater from Masaryktown to Crews Lake. The 20-foot deep by 50-foot wide canal cuts through and drains water from the northern part of the well field during periods of heavy rainfall. Although flow in the canal is not gaged, it is known to be zero during most of the year.

The Cross Bar Ranch well field is drained primarily by Jumping Gully, which discharges into Crews Lake. For the 17-year period of record from October 1964 to September 1981, the average runoff from the stream's 43-mi^2 drainage area east of U.S. Highway 41 was 2.2 in/yr. This was mostly flood flow. Most of the base flow was retained by a dam on the east side of the highway.

Lakes in the study area are considered conceptually to be "windows" in the surficial aquifer through which the water table can be observed. Hydrographs of the stages of Crews Lake, Pasco Lake, and Triangle Lake and the water table in wells WRW shallow and S1 for the period 1977-82 are shown in figure 13. Also shown are pumpage and rainfall data.

Crews Lake, 2 miles west of the well field, exemplifies the internal drainage of the Lakes Terrace physiographic unit (fig. 2). Crews Lake is less than 20 feet deep, has a surface area of 1.2 mi^2, and is divided into two nearly equal parts by a dike. Water from Jumping Gully flows into the lake, forming the headwaters of the Pithlachascotee River, and then flows southwestward to the Gulf of Mexico. There probably is little downward leakage through the bed of the lake in the wet season because the potentiometric surface of the Upper Floridan aquifer is at about the same level as the lake. In dry seasons, pumping and differences in confined and unconfined storage factors cause the potentiometric surface of the Upper Floridan aquifer to decline more rapidly than the level of the lake. This causes drainage through a sinkhole in the northern part of the lake and virtually dries up the lake north of the dike. During these periods, flow is north through a culvert in the dike rather than the usual southerly direction. Flow into the sinkhole has been estimated at 20 to 25 ft^3/s or 13 to 16 Mgal/d (U.S. Geological Survey, Sixth Advanced Ground-Water Seminar, unpublished field trip guidebook, 1970).

Pasco Lake was formed by dredging and damming of Jumping Gully. Stages of Pasco Lake and the water table at nearby shallow well S1 generally parallel water levels measured at other sites during periods of near normal rainfall. However, during drought and wet periods, their water levels fall or rise more rapidly than those of other nearby sites. This can be seen in figure 13 by comparing levels of Pasco Lake and well S1 with Triangle and Crews Lakes during the drought periods of late 1978 and late 1980 to mid-1981 and the subsequent recovery periods of early 1979 and mid-1982.

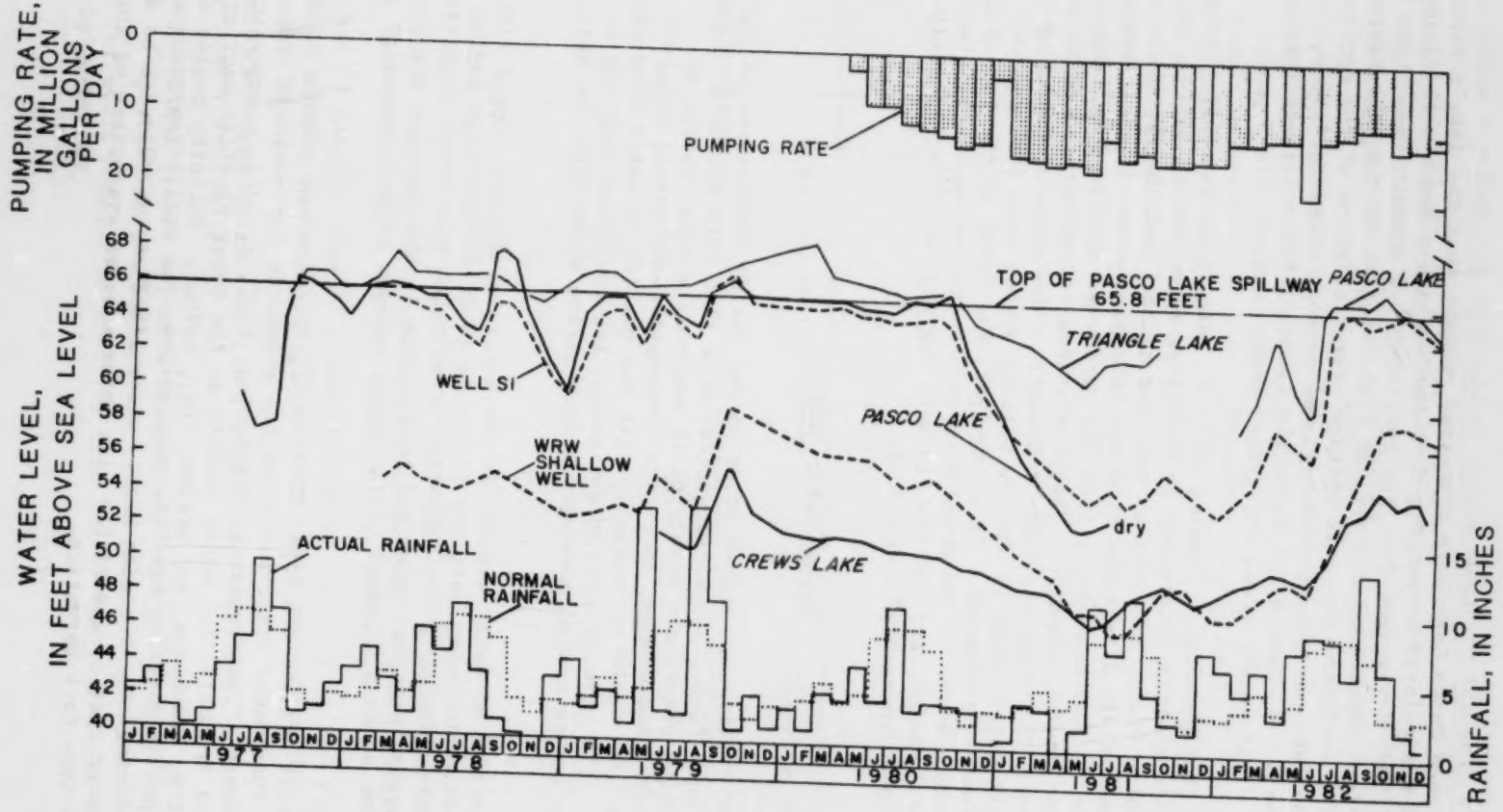

Figure 13.--Relations between lake stage and ground-water levels, rainfall, and pumping, 1977-82.

Homeowners around Pasco Lake have expressed concern that the lake's rapid decline in 1980-81 was related to pumping from the Cross Bar Ranch well field. Gilboy and Moore (1982) determined that the confining bed beneath Pasco Lake is between 42 and 79 feet below land surface and that dredging of the lake bottom had not breached the confining bed. If leakage characteristics of the confining bed beneath the lake correspond with regional leakage characteristics, pumping from the well field would not cause the level of Pasco Lake to decline more rapidly than other nearby lakes and ground-water levels.

It is likely that damming of Jumping Gully to form Pasco Lake had created a ground-water mound that is maintained by discharge from Jumping Gully. When flow in Jumping Gully stops, recharge to the lake ceases, and the mound decays by lateral movement in all directions from the lake plus some vertical leakage. In contrast, water is lost regionally from the surficial aquifer more from vertical leakage than lateral movement. These relations are substantiated in the hydrograph of figure 13 during the 1980-81 drought. The stage of Pasco Lake was higher than the water table in shallow well S1 during late 1980 due to buildup of the ground-water mound. In early 1981, the level of the lake fell below the water table in S1 as the mound decayed. Water had not spilled out of Pasco Lake for 3 months, and the east to west regional water-table gradient probably was restored to natural conditions.

Ground-Water Quality

Ground-water quality was tested prior to and during development of the Cross Bar Ranch well field. Chemical-quality data that were collected during drilling and testing phases are tabulated in numerous status reports by Leggette, Brashears, and Graham, Inc. The consumptive-use permit requires operators of the well field to routinely test the quality of water from each production well. The primary concern and reason for continued sampling are that pumping may induce upward movement of deep saline water into the producing zone.

Typical analyses of water quality in the surficial aquifer, Upper Floridan aquifer, and middle confining unit are listed in table 4. Although sodium and potassium concentrations were not reported, it is known that these minerals are prevalent in Florida's ground water and that sodium is the dominant mineral. Sodium was estimated as a residual of the ionic balance between the major anions and cations.

The surficial aquifer and Upper Floridan aquifer contain calcium bicarbonate type water that meets State water-quality standards for municipal supply (Florida Department of Environmental Regulation, 1982, p. 102). Geophysical logs of well B-1 indicate that water quality in the Upper Floridan aquifer is uniform (Leggette, Brashears, and Graham, Inc., 1979e). Salinity begins to increase at a depth of 960 feet near the contact with the middle confining unit. The middle confining unit contains highly mineralized sodium chloride to sodium sulfate type water that is associated with intergranular evaporites of the lower part of the Avon Park Formation.

Table 4.--Chemical analyses of ground water in the well field

Hydrogeologic unit	Surficial aquifer[1/]	Upper Floridan aquifer[2/]	Middle confining unit[3/]
Depth of well (feet)	25	688	1,260
Depth of casing (feet)	22	146	1,235
Date of sample	1978-79	12-14-82	8-9-79
Bicarbonate (mg/L)	72	227	396
Chloride (mg/L)	8	11.1	7,250
Sulfate (mg/L)	4	1.7	3,920
Calcium (mg/L)	13	71.5	848
Magnesium (mg/L)	6	2.7	462
Sodium (mg/L)[4/]	8	70	4,800
Iron (mg/L)	2	.2	15
Dissolved solids (mg/L)	85	215	18,930

Production wells

Well	Dissolved-solids concentration[5/] (mg/L)	Well	Dissolved-solids concentration[5/] (mg/L)
CB-1	219	CB-10	197
CB-2	219	CB-11	188
CB-3	219	CB-12	190
CB-4	221	CB-13	190
CB-5	226	CB-14	204
CB-6	201	CB-15	225
CB-7	190	CB-16A	181
CB-8	202	CB-17	193
CB-9	210		

[1/] Estimated from partial analyses of samples from 14 wells (Leggette, Brashears, and Graham, Inc., 1979d, appendix VII, table 5).

[2/] Average of samples from 17 production wells reported by the West Coast Regional Water Supply Authority in the December 1982 monthly report for Cross Bar Ranch well field.

[3/] Sample from deep monitor well B-1 (Leggette, Brashears, and Graham, Inc., 1980c, appendix V, table 5).

[4/] Sodium concentrations were estimated as residual of the ionic balance: $(HCO_3 + Cl + SO_4) - (Mg + Ca) \simeq Na$.

[5/] Data for wells sampled on 10/27/81 supplied by the West Coast Regional Water Supply Authority.

Figure 14 shows the dissolved-solids concentration in water from the producing zone and relates the concentrations to pumping from the well field. The graph indicates that dissolved-solids concentrations in water from production well CB-7 range between about 180 mg/L and 270 mg/L. There has not been any significant change in water quality since the well was first tested in 1978. There is little or no indication of saline water leaking upward through the confining unit at the base of the Upper Floridan aquifer, although upconing might not be detected for a long time. The dissolved-solids concentration in water from production well CB-7 is similar to concentrations in other production wells (table 4) and closely matches that of the blended water from all wells influent to the treatment plant (fig. 14). Analysis of figure 14 and table 4 indicates that, areally, the Upper Floridan aquifer contains water of uniform quality.

HYDROLOGIC CYCLE

Elements of the hydrologic cycle in west-central Florida are rainfall, surface and subsurface runoff, evapotranspiration (ET), leakage to or from the Upper Floridan aquifer, pumping, and changes in amounts of water in storage in the surficial and Upper Floridan aquifers. In the ground-water model analysis, all time-dependent hydrologic parameters, including ground-water levels, are considered as long-term averages; therefore, short-term fluctuations in amounts of water in storage in the surficial and Upper Floridan aquifers are neglected. Pumping from the surficial aquifer is so small that it is neglected.

The nearest rain gages with long-term data operated by the National Oceanic and Atmospheric Administration are at Chinsegut Hill, 14 miles north of the well field, and at St. Leo, about 18 miles to the east (fig. 1). In west-central Florida, mean annual rainfall is about 55 inches and is seasonally distributed as about 7 inches in winter, 10 inches in spring, 25 inches in summer, and 13 inches in autumn (Hughes and others, 1971). Aquifers gradually become depleted in the winter and spring when pumping, natural outflow, and ET exceed recharge. Aquifers are replenished by summer and autumn rains.

Runoff from the Cross Bar Ranch area is low. Much of the area is "internally drained" in that surface runoff flows into sinkholes or lakes where it eventually leaks downward or evaporates. Surface runoff from the well field is primarily through Jumping Gully, which flows into Crews Lake. The gaged outflow for the 17-year period of record from October 1964 to September 1981 was shown to be 2.2 in/yr, or about 4 percent of the total rainfall.

ET is a major component of the hydrologic cycle in west-central Florida. It occurs in essentially three modes involving either evaporation or transpiration: (1) from plant surfaces, open-water bodies, and bare ground; (2) from the unsaturated zone (above the water table but beneath land surface); and (3) from the water table. The potential ET from a free-water surface in west-central Florida is about 46 to 50 in/yr (Koehler and others, 1959; Dohrenwend, 1977). However, actual ET is less than the potential in much of west-central Florida. In areas where the water table is far below land surface, water in the surficial aquifer is less subject to uptake by plants (transpiration) or direct evaporation than where the water table is at or near land surface.

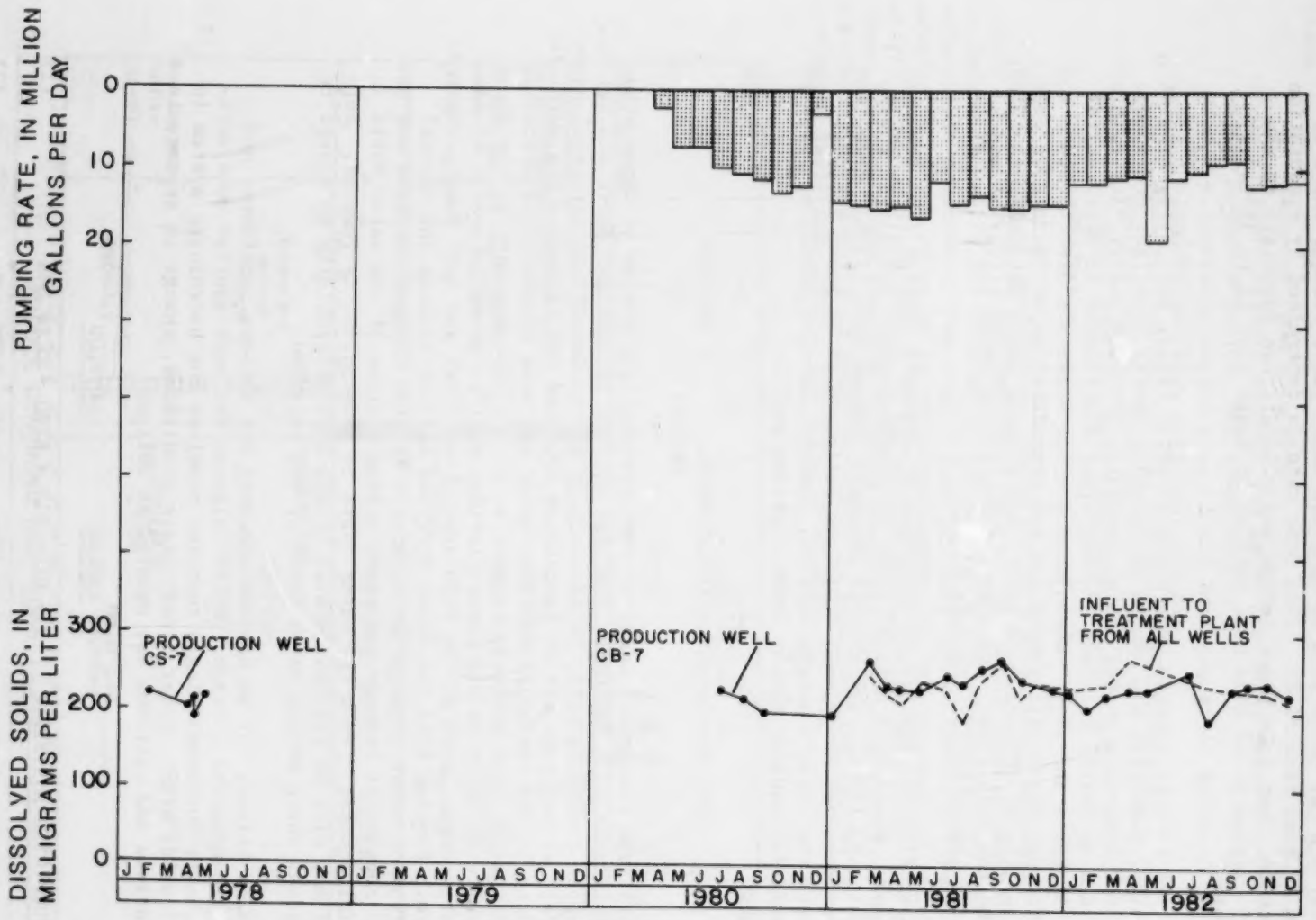
PUMPING RATE, IN MILLION GALLONS PER DAY
0
10
20
DISSOLVED SOLIDS, IN MILLIGRAMS PER LITER
300
200
100
0
PRODUCTION WELL CS-7
PRODUCTION WELL CB-7
INFLUENT TO TREATMENT PLANT FROM ALL WELLS
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1978
1979
1980
1981
1982

Figure 14.--Concentrations of dissolved solids in water from the producing zone.

No matter how far below land surface the water table stands, there is some minimum or base rate of ET. This base rate is determined by evaporation and transpiration that take place before any rainfall can percolate to the water table. Estimates of this base rate of ET range from 25 to 35 in/yr (Tibbals, 1978).

The actual ET rate depends upon depth to water table, soil type, type of plant community, humidity, and amount of incoming energy (sunlight and wind). On an areal and long-term annual basis, humidity, incoming energy, and rainfall can be regarded as fairly constant and uniformly distributed in west-central Florida. Soil types and plant communities are not uniformly distributed. For modeling purposes, these differences are not considered major factors in determining variability of ET because depth to water table helps determine the plant community and the soil type. Therefore, depth to the water table is used as the factor for proportioning the rate of ET.

The Upper Floridan aquifer is recharged by downward leakage from the surficial aquifer. Based on a digital model of predevelopment hydrologic conditions (Hutchinson, 1984a), the average downward leakage in a 121-mi^2 area that includes the Cross Bar Ranch well field was estimated to be about 13 in/yr. Pumping lowers the potentiometric surface, thereby inducing additional leakage from the surficial aquifer to the Upper Floridan aquifer.

CONCEPTUAL MODEL

A generalized conceptual model of the hydrogeologic system is shown schematically in figure 15. The Upper Floridan aquifer is confined above and below. Above the upper confining unit, it is overlain by the unconfined surficial aquifer. Rainfall either runs off or percolates downward and recharges the surficial aquifer. Once in the surficial aquifer, water may move laterally to discharge where it intersects land surface, be lost as ET, or leak downward to the Upper Floridan aquifer. Water in the Upper Floridan aquifer moves laterally to lowland discharge areas, such as the Pithlachascotee River and Gulf Coast, where it leaks upward. Pumping from the Upper Floridan aquifer reduces the natural coastward flow of water through the aquifer. It also changes the rate and possibly the direction of leakage and results in a decline of the water table in the surficial aquifer. When the water table is lowered, ET is reduced. Surface runoff may also be reduced because of the aquifer's ability to accept recharge in areas where excess water formerly was rejected.

The water balance for an aquifer accounts for inflows, outflows, and changes in ground-water storage. Water balances for each aquifer were estimated as a basis for developing a computer model of the hydrologic system in the 121-mi^2 study area. Under steady-state conditions, change in storage is zero and inflows and outflows are equated as follows:

	INFLOW		OUTFLOW	
SURFICIAL AQUIFER:	R + UL + BIS	=	ETRO + DL + BOS	(1)
UPPER FLORIDAN AQUIFER:	DL + BIUF	=	UL + BOUF + P	(2)

where

R = recharge from rainfall;
UL = upward leakage through the upper confining unit;
BIS = boundary inflow, surficial aquifer;
ETRO = evapotranspiration plus runoff from the water table;
BOS = boundary outflow, surficial aquifer;
DL = downward leakage through the upper confining unit;
BIUF = boundary inflow, Upper Floridan aquifer;
BOUF = boundary outflow, Upper Floridan aquifer; and
P = pumpage.

Under normal climatological conditions with no pumping, estimated total inflow to the surficial aquifer is 28 in/yr. Surficial aquifer boundary outflow or inflow is negligible because of the aquifer's low transmissivity and low water-table gradient. Less than 0.1 in/yr leaks upward from the Upper Floridan aquifer, so about 28 in/yr is recharge computed as the residual of rainfall (55 in/yr) minus overland runoff (2 in/yr) and minimum base rate of ET (25 in/yr). About 13 in/yr leaks downward from the surficial aquifer to the Upper Floridan aquifer. The remaining 15 in/yr of inflow is lost from the aquifer as ET from the water table and lateral discharge to streams.

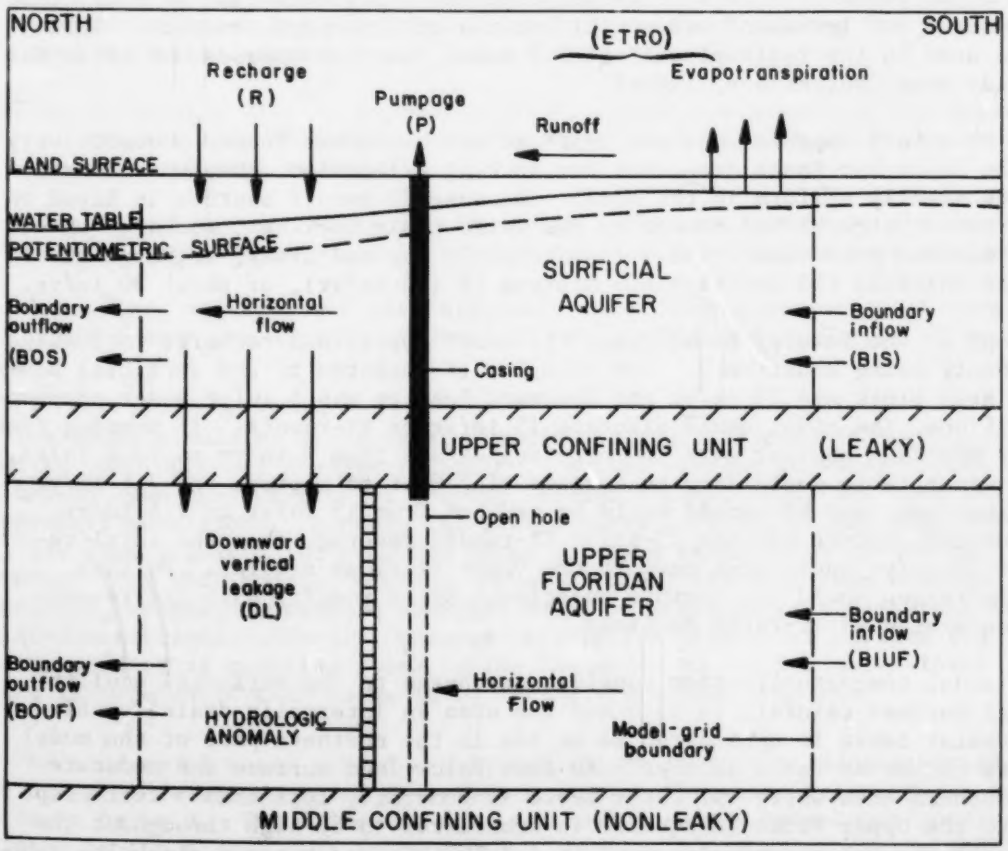

Figure 15.--Conceptual model of the hydrogeologic system.

The Upper Floridan aquifer receives inflow by downward leakage and ground-water flow across the boundary from outside the model grid. Under nonpumping conditions, downward leakage averages about 13 in/yr and boundary inflow about 2 in/yr. This water is lost through boundary outflow of about 15 in/yr and upward leakage of less than 0.1 in/yr.

The water balance within the surficial aquifer may be altered significantly by pumping from the Upper Floridan aquifer. Pumping induces downward leakage, thereby lowering the water table. Surface-water runoff, ET, and ground-water discharge to streams (the three combined are referred to hereafter as ET-runoff) may be reduced when the water table is lowered. In the model, these reductions are computed by an ET-runoff capture function that relates the rate of capture to water-table depth. In the model conceptualization, it is assumed that all ET from the water table (15 inches) plus approximately half the runoff (1 inch) could be salvaged by lowering the water table from its average depth to 10 feet below land surface. It is recognized that this may not be practical from a management standpoint because widespread lowering of water levels could dry up lakes, alter natural vegetation, cause pump failure in shallow wells, and induce sinkhole development. Although ET from the water table is shut off, there probably would be an increase in uncapturable ET from the much thicker unsaturated zone. The ET-runoff capture rate has not been verified by field measurements; however, model results of this study indicate that, for each foot of water-table decline, about 3.8 inches of water will not run off or evapotranspire. This value was used in the regional well-fields model that encompasses the Cross Bar Ranch study area (Hutchinson, 1984a).

The ET-runoff capture rate and depth at which capture ceases probably vary within the Cross Bar Ranch area, but for lack of validation, they were considered to be areally uniform in the model. Because ET-runoff capture is based on reducing water-table ET and runoff as the water table declines, recharge should approach maximum potential rates. In internally drained areas, recharge should not exceed rainfall (55 in/yr) minus minimum ET (25 in/yr), or about 30 in/yr.

Except at the lateral boundaries, the model apportions recharge to leakage and ET-runoff using equation 1. For example, if recharge to the surficial aquifer in a grid block was 20 in/yr and downward leakage was 5 in/yr under nonpumping conditions, the model would allocate 15 in/yr as ET-runoff. If pumping from the Upper Floridan aquifer were to increase leakage from 5 in/yr to 12.6 in/yr, then the water table would drop an average of 2 feet to capture the 7.6-in/yr leakage increase, and ET-runoff would be reduced from 15 in/yr to 7.4 in/yr. Should pumping capture all the 15-in/yr ET-runoff reserve, then the total recharge of 20 in/yr would leak down to the Upper Floridan aquifer. Further pumping increases would not capture additional ET or runoff, with the result being accelerated water-table declines.

The model conceptualization considers recharge to the surficial aquifer to be high because rainfall is high and the area is internally drained. ET from the water table is considered to be low in the northern part of the model area where the water table is nearly 10 feet below land surface and moderate in the southern area where the water table is generally less than 5 feet deep. Leakage to the Upper Floridan aquifer is considered to be high throughout the area because the upper confining unit is fairly thin and because sinkholes probably increase the leakage rate. Transmissivity of the surficial aquifer is very low relative to transmissivity of the Upper Floridan aquifer.

SIMULATED IMPACT OF PUMPING

Digital models of steady-state ground-water flow were utilized in this study to improve the understanding of hydrogeologic conditions and the impact of pumping from the Cross Bar Ranch well field on the hydrogeologic system. A regional model of a 932-mi^2 area (Hutchinson, 1984a) was used to provide boundary flows for input into a local model of the 121-mi^2 study area. This nested modeling technique allowed the study area to be small and still allowed for simulation of regional interference caused by pumping from wells outside the study area. The model program and modeling procedures are described in the "Supplemental Data" section.

Four combinations of hydrologic conditions and well-field operation were simulated using the nested modeling technique.

1. Predevelopment conditions, with no pumping.--Long-term average conditions with no stresses are simulated. The heads from this simulation are used as initial conditions for subsequent model runs.

2. Regional pumping adjacent to Cross Bar Ranch.--This model run simulates impact at Cross Bar Ranch resulting from regional pumping for irrigation and municipal supply.

3. Pump 30 Mgal/d, with no regional pumping.--This run simulates the impact on the aquifers of pumping the Cross Bar Ranch well field at its average annual permitted rate.

4. Pump 45 Mgal/d, with no regional pumping.--This run simulates the impact on the aquifers of pumping the well field at its maximum permitted rate.

Inflow, outflow, and drawdown were simulated under each combination of conditions to determine the sources of water and the extent and magnitude of pumping effects.

The model simulates steady-state conditions where changes in outflow caused by pumping equal changes in inflow. Actual changes in water levels and flow depend upon the duration of pumping, boundary conditions, and upon transient rainfall conditions. Because the steady-state analysis is not time dependent, the time required for computed heads to reach equilibrium cannot be determined from this model. Because the model simulates long-term average water-level changes, short-term extremes could be significantly different from simulated conditions. Finally, because calibration errors are carried over into the predictive modeling phase, using the model to predict water-level changes is more valid than using it to define a new head condition.

The sources of water pumped are determined by comparing model-computed water balances developed using equations 1 and 2. The water balances are summarized in table 5. The following four sections describe hydrologic conditions simulated by the model. The fifth section concerns limitations of the model analysis.

Table 5.--Summary of water-balance and water-level data simulated by the model under varying conditions of pumping

A. WATER BALANCE FOR SURFICIAL AQUIFER

	R Recharge (in/yr)	BI Boundary inflow (in/yr)	ETRO ET-runoff from water table (in/yr)	UL Upward leakage (in/yr)	DL Downward leakage (in/yr)	BO Boundary outflow (in/yr)
Predevelopment conditions ---	28	<0.1	14.7	<0.1	13.3	<0.1
Pump adjacent to Cross Bar Ranch --------	28	<0.1	13.4	<0.1	14.6	<0.1
Pump 30 Mgal/d -------	28	<0.1	11.5	<0.1	16.5	<0.1
Pump 45 Mgal/d -------	28	<0.1	10.1	<0.1	17.9	<0.1

Water balance: R + UL + BIS = ETRO + DL + BOS

B. WATER BALANCE FOR UPPER FLORIDAN AQUIFER

	UL Upward leakage (in/yr)	DL Downward leakage (in/yr)	BIUF Boundary inflow (in/yr)	BOUF Boundary outflow (in/yr)	Pumpage (in/yr)
Predevelopment conditions ---	<0.1	13.3	1.5	14.8	0.0
Pump adjacent to Cross Bar Ranch ----------	<0.1	14.6	1.3	15.9	0.0
Pump 30 Mgal/d ----------	<0.1	16.5	1.6	12.9	5.2
Pump 45 Mgal/d ----------	<0.1	17.9	1.7	11.8	7.8

Water balance: DL + BI = UL + BO + P

C. AVERAGE DRAWDOWN OVER MODEL AREA

	Water table in surficial aquifer (feet)	Potentiometric surface of Upper Floridan aquifer (feet)
Predevelopment conditions ----------	0.0	0.0
Pump adjacent to Cross Bar Ranch ----------	0.3	0.6
Pump 30 Mgal/d ----------	2.4	4.0
Pump 45 Mgal/d ----------	4.6	6.9

Predevelopment Conditions, With No Pumping

An estimate of hydrologic conditions prior to development of ground-water resources was necessary to simulate the impact of development. The predevelopment simulation represents inflow, outflow, and water levels under long-term average climatic conditions with no pumping, either locally or regionally. It is the basis for comparing subsequent model runs that simulate effects of ground-water withdrawal on the hydrologic system. The model-simulated water table in the surficial aquifer and potentiometric surface of the Upper Floridan aquifer are shown in figures 16 and 17.

The average model-simulated predevelopment water table and potentiometric surface (figs. 16 and 17) are slightly higher than those observed for the September 1976 to May 1977 validation period (figs. 8 and 9). Predevelopment water levels represent a period of average rainfall (55 in/yr), whereas validation levels reflect a 51.6-in/yr rainfall condition. The average water levels for validation were also slightly lowered by regional pumping outside the modeled area. The water balance for the surficial aquifer (table 5) indicates that under predevelopment conditions, boundary flow is negligible, and of the 28-in/yr recharge to the water table, about half leaves the aquifer as ET-runoff and about half leaks downward to the Upper Floridan aquifer. Hence, the water balance indicates that downward leakage from the surficial aquifer is an important source of recharge to the Upper Floridan aquifer. Lateral inflow to the Upper Floridan aquifer accounts for only 1.5 in/yr due to the relatively flat hydraulic gradient along the southern boundary of the modeled area.

Regional Pumping Adjacent to Cross Bar Ranch

From a water-resources management standpoint, it is useful to estimate how the Cross Bar Ranch well field is affected by regional pumping for municipal supply and irrigation. An average permitted pumping rate of 157 Mgal/d for nine municipal well fields plus 53 Mgal/d for irrigation was simulated by the regional model (Hutchinson, 1984a) that includes the nonpumping Cross Bar Ranch well-field area. The regional model simulated the change in flow at the Cross Bar Ranch model boundary. Predevelopment boundary flows in the Upper Floridan aquifer in the Cross Bar Ranch model were then adjusted to reflect these changes. The model was then run with the new constant-flow boundary condition to simulate localized effects of regional pumping adjacent to the well field.

Model-simulated drawdowns in the surficial and Upper Floridan aquifers, resulting from regional pumping, are shown in figures 18 and 19. Across the modeled area, drawdown averages 0.3 foot in the water table and 0.6 foot in the potentiometric surface of the Upper Floridan aquifer (table 5). Drawdowns are greatest in the southeast part of the modeled area, primarily due to pumping of 30 Mgal/d from the nearby Cypress Creek well field. Within the Cross Bar Ranch well field, maximum drawdowns caused by regional pumping occur at the southeast corner of the well field. There, the water table and potentiometric surface have been drawn down about 0.6 foot and 1 foot, respectively. The least impact occurred at the northern boundary of the well field where drawdown in each aquifer was less than 0.2 foot.

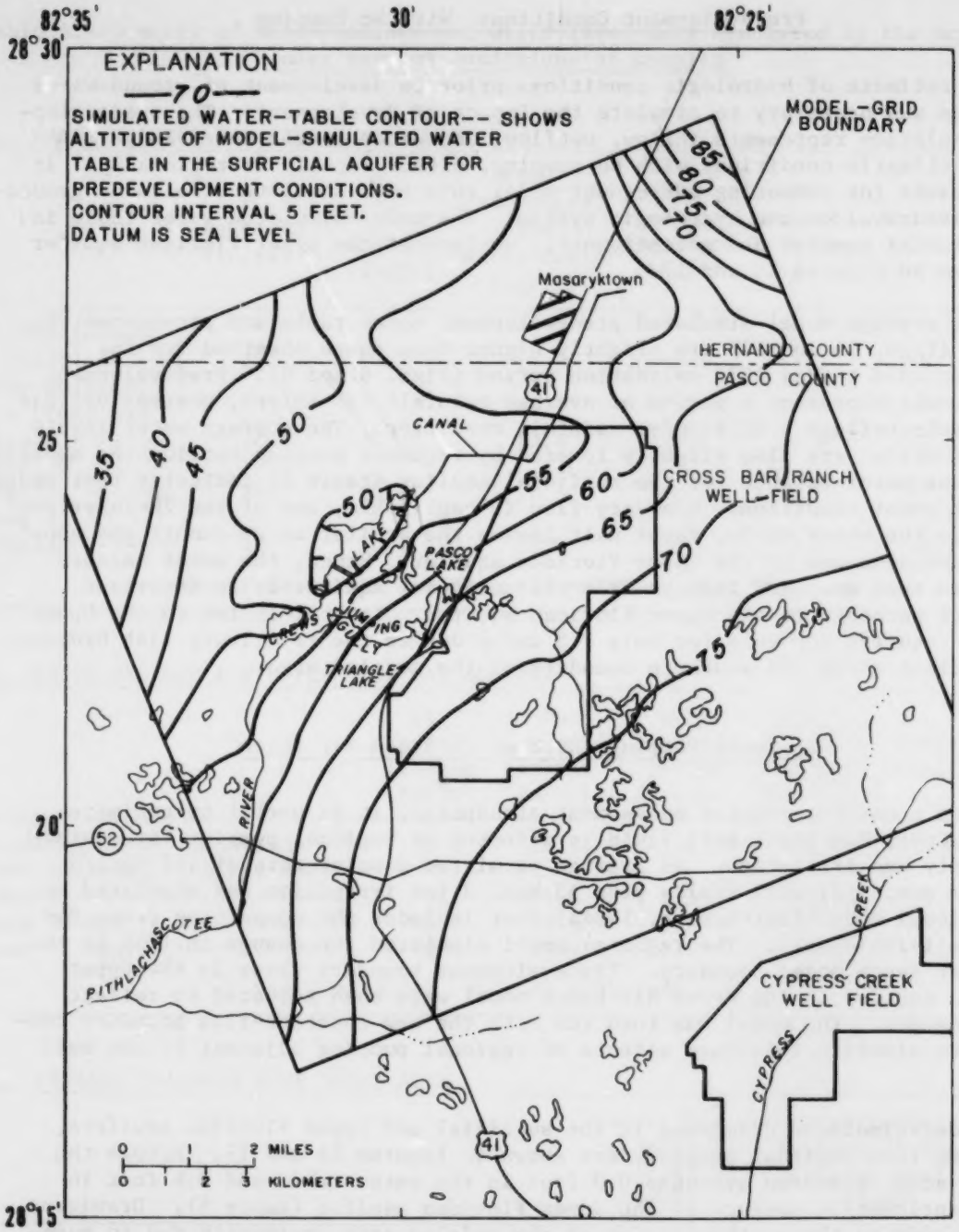

Figure 16.--Model-simulated water table in the surficial aquifer for predevelopment conditions.

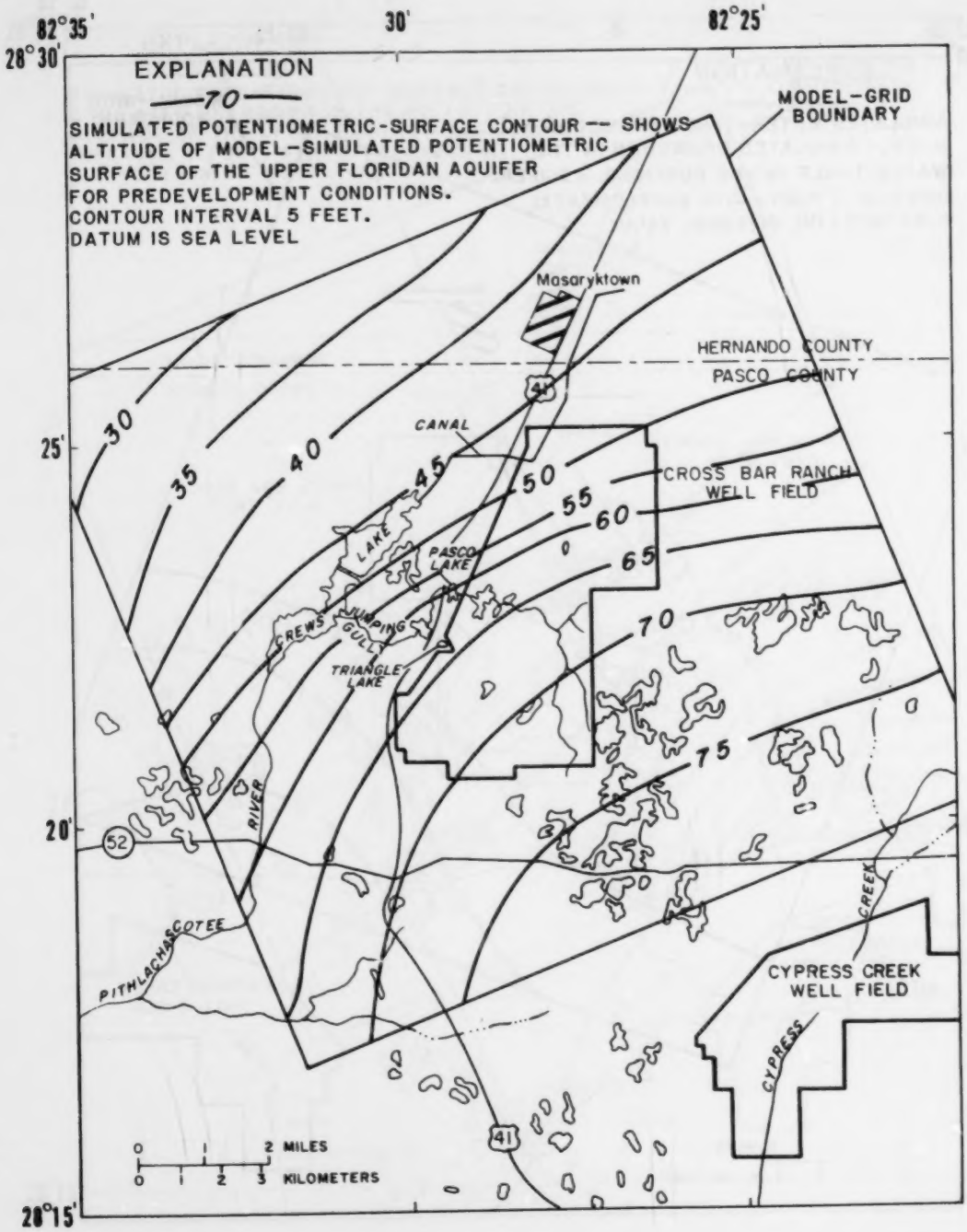

Figure 17.--Model-simulated potentiometric surface of the Upper Floridan aquifer for predevelopment conditions.

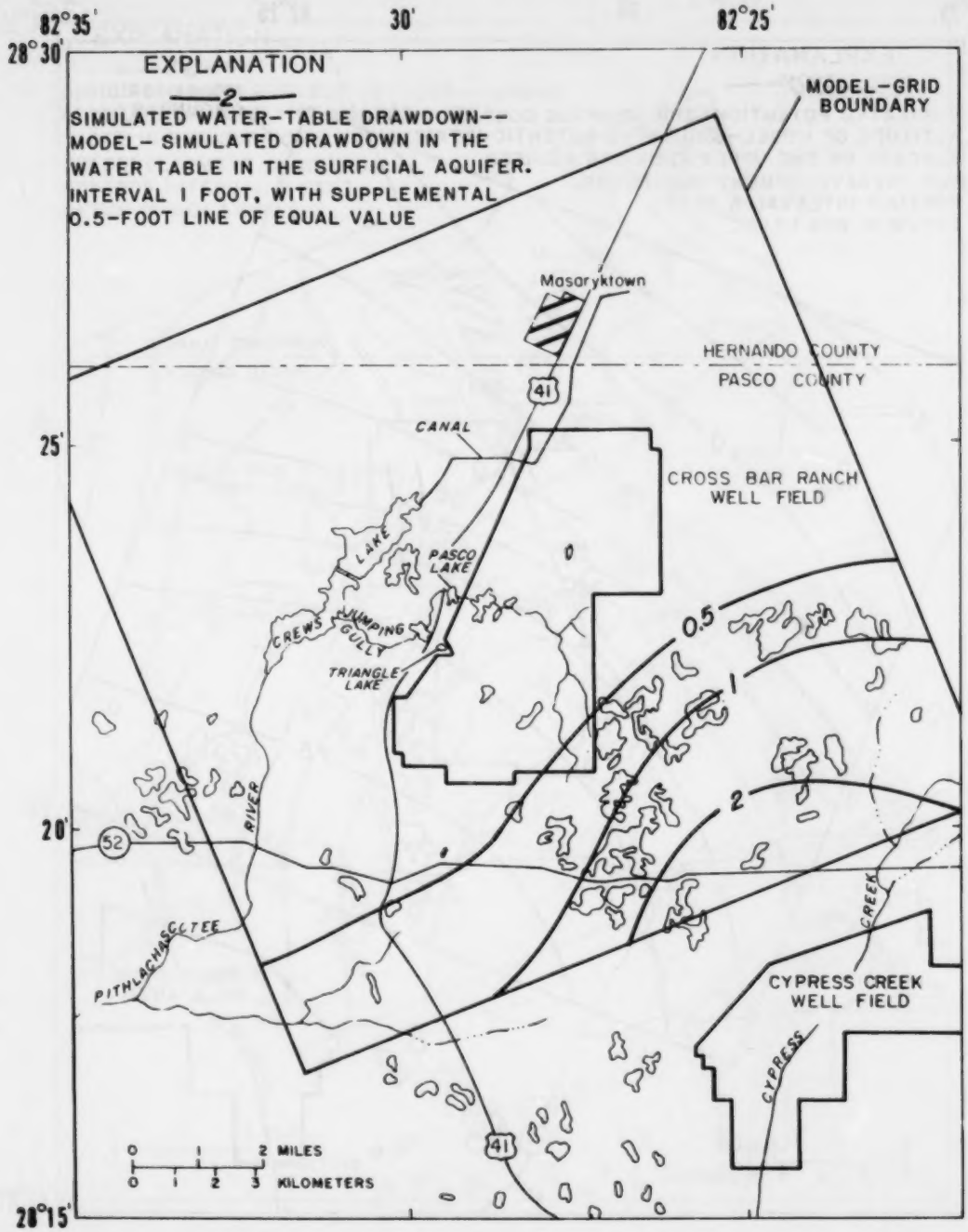

Figure 18.--Model-simulated drawdown in the water table in the surficial aquifer, resulting from regional pumping adjacent to the Cross Bar Ranch well field.

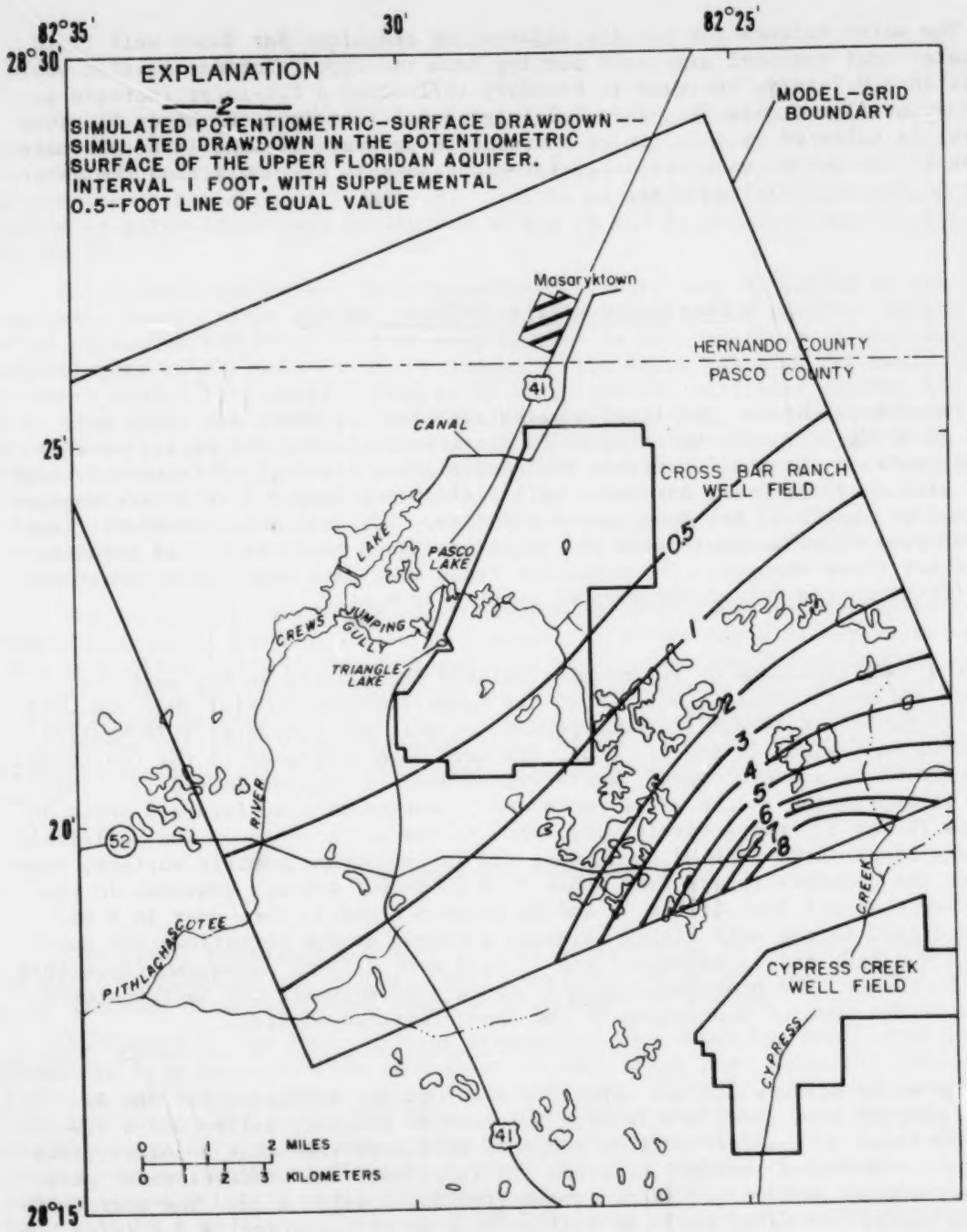

Figure 19.--Model-simulated drawdown in the potentiometric surface of the Upper Floridan aquifer, resulting from regional pumping adjacent to the Cross Bar Ranch well field.

The water balance for pumping adjacent to the Cross Bar Ranch well field indicates that regional simulated pumping from the Upper Floridan aquifer would result in a 0.2-in/yr decrease in boundary inflow and a 1.1-in/yr increase in boundary outflow (table 5). This 1.3-in/yr total loss from the Upper Floridan aquifer is balanced by a 1.3-in/yr increase in downward leakage. The ultimate source of the pumped water is a 1.3-in/yr net loss in ET-runoff from the water table in the surficial aquifer.

Pumping 30 Million Gallons Per Day

The average annual permitted pumping rate for the Cross Bar Ranch well field is 30 Mgal/d. The modeling procedure for simulating the impact of this pumping rate on the aquifer system included running the regional predevelopment model with only the Cross Bar Ranch well field being pumped to simulate changes in flows at the Cross Bar Ranch model boundary. Predevelopment boundary flows in the Upper Floridan aquifer in the Cross Bar Ranch model were then adjusted to reflect these changes. The Cross Bar Ranch model was then run to simulate the effects on the well-field area of pumping 30 Mgal/d.

The configurations of the model-simulated water table in the surficial aquifer and potentiometric surface of the Upper Floridan aquifer when the well field is pumped at 30 Mgal/d (each production well was pumped at 1.76 Mgal/d) are shown in figures 20 and 21. Contours have been displaced to the southeast with respect to predevelopment levels represented in figures 16 and 17. The cones of depression in the water table and potentiometric surface are shown in figures 22 and 23, respectively. Drawdown in the water table at the well-field boundary ranges from about 2 to 9 feet, and in the potentiometric surface, drawdown at the boundary ranges from about 3 to 10 feet. Average drawdown in the water table is 2.4 feet (table 5) and is between 5 and 17 feet over an 8-mi^2 area centered in the well field. Average drawdown in the potentiometric surface is 4.0 feet and is between 5 and 21 feet over a 15-mi^2 area, mostly within the well field. The hydrologic anomaly appears to restrict the northwesterly spread of the cone of depression in the Upper Floridan aquifer.

The water balance for the Upper Floridan aquifer simulated for the 30-Mgal/d pumping rate shows a 0.1-in/yr increase in boundary inflow and a 1.9-in/yr decrease in boundary outflow compared with predevelopment boundary flows (table 5). Downward leakage increases 3.2 in/yr over the predevelopment rate to provide the total of 5.2 in/yr pumped from the modeled area. The increased leakage causes the water table to decline to a level resulting in 3.2 in/yr being captured from ET-runoff. ET-runoff capture ceased in 164 grid blocks where the water table declined to more than 10 feet below land surface. Consequently, average drawdown was greater than the 0.84 foot anticipated on the basis of the conceptual model (3.8 in/yr of ET-runoff is captured per foot of drawdown in the water table).

Pumping 45 Million Gallons Per Day

The maximum daily permitted pumping rate for the Cross Bar Ranch well field is 45 Mgal/d for short time periods. Modeling procedures for simulating the impact of this pumping were the same as those used to simulate the effects of pumping at the rate of 30 Mgal/d. Results of the model simulations are depicted by water-level maps in figures 24 and 25 and by drawdown maps in figures 26 and 27.

Water-table and potentiometric-surface contours were displaced to the southeast about 1 mile further than the displacement for 30 Mgal/d. Extensive cones of depression 20 to 25 feet deep develop in both aquifers in the north-central part of the well field. Drawdown in the water table at the well-field boundary ranges from about 3 feet to 15 feet, and the surficial aquifer has been completely dewatered in three grid blocks (fig. 26). Drawdown in the potentiometric surface ranges from about 30 feet in the center of the well field to about 5 to 20 feet at the well-field boundary. Average drawdown in the water table is 4.6 feet (table 5) and is between 5 and 26 feet over a 16-mi^2 area centered around the pumping. Average drawdown in the potentiometric surface is 6.9 feet and is between 5 and 35 feet over a 28-mi^2 area that includes the well field.

The water balance for the Upper Floridan aquifer under the 45-Mgal/d pumping condition shows a 0.2-in/yr increase in inflow and a 3.0-in/yr reduction in outflow along the model boundaries with respect to predevelopment conditions. Downward leakage increases 4.6 in/yr to provide part of the total of 7.8 in/yr pumped from the well field. The increased leakage is water captured by reducing ET-runoff from the water table in the surficial aquifer. ET-runoff capture ceased in 222 grid blocks resulting in accelerated drawdown in the water table.

SUMMARY AND CONCLUSIONS

The 13-mi^2 Cross Bar Ranch well field is scheduled to provide 30 Mgal/d of water to Pinellas and western Pasco Counties. This study of the well-field area has been directed toward specific objectives as follows:

1. Describe the hydrogeologic framework.--The Cross Bar Ranch area is blanketed by a layer of fine sand about 35 feet thick that forms the low-yielding surficial aquifer. A sand and clay bed, 10 to 20 feet thick, underlies the surficial aquifer and forms a leaky upper confining unit between the surficial aquifer and the underlying Upper Floridan aquifer. The major producing zone is the Upper Floridan aquifer that is composed of a sequence of limestone and dolomite about 900 feet thick. The Upper Floridan aquifer is underlain by a middle confining unit of limestone and dolomite with porosity plugged by intergranular gypsum and anhydrite.

Under natural conditions, the water table in the surficial aquifer and the potentiometric surface of the Upper Floridan aquifer generally lie within 10 feet of land surface. Because the Upper Floridan aquifer is highly transmissive and the upper confining unit is moderately leaky, pumping large quantities of water from a small area, such as the well field, induces broad cones

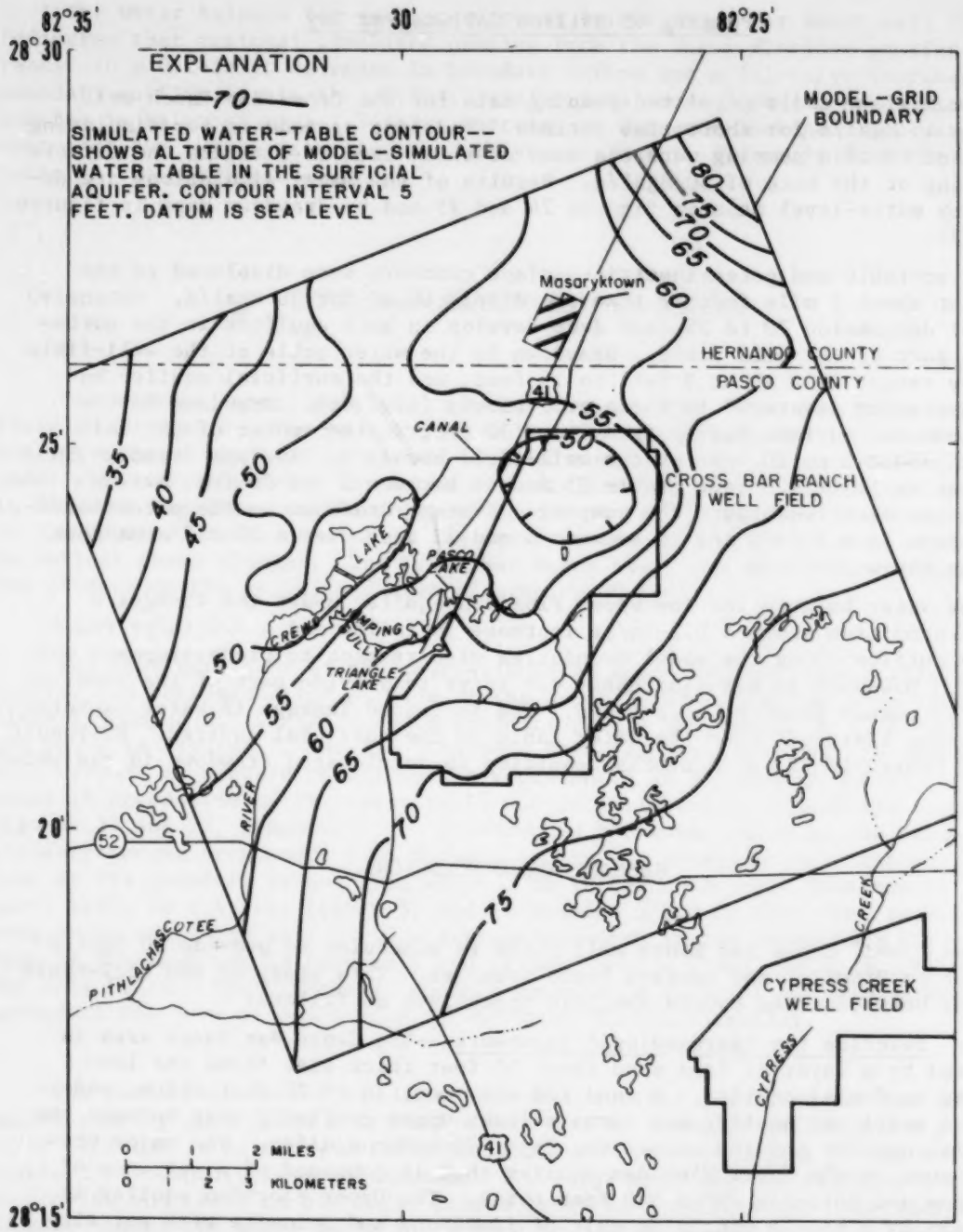

Figure 20.--Model-simulated water table in the surficial aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day.

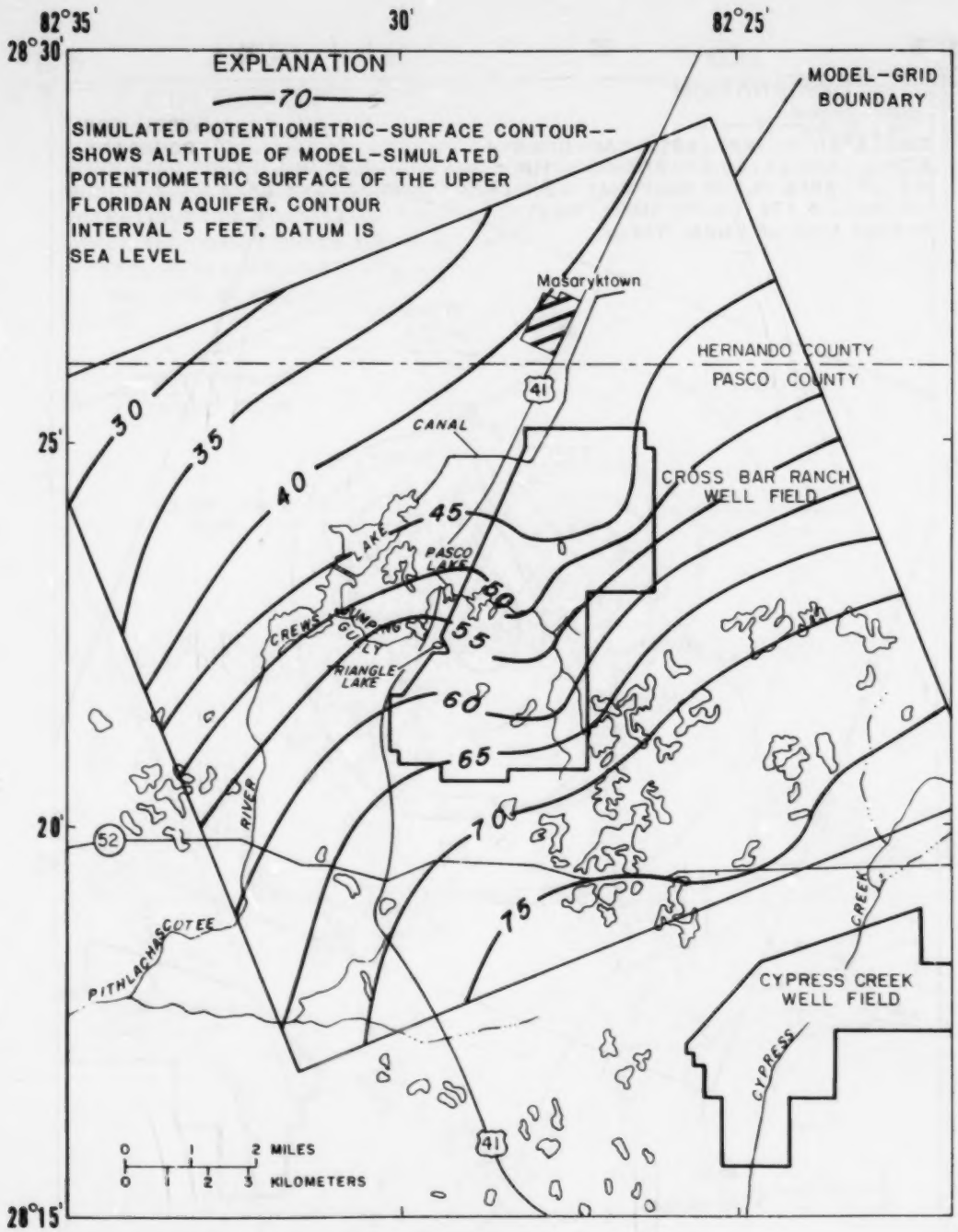

Figure 21.--Model-simulated potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day.

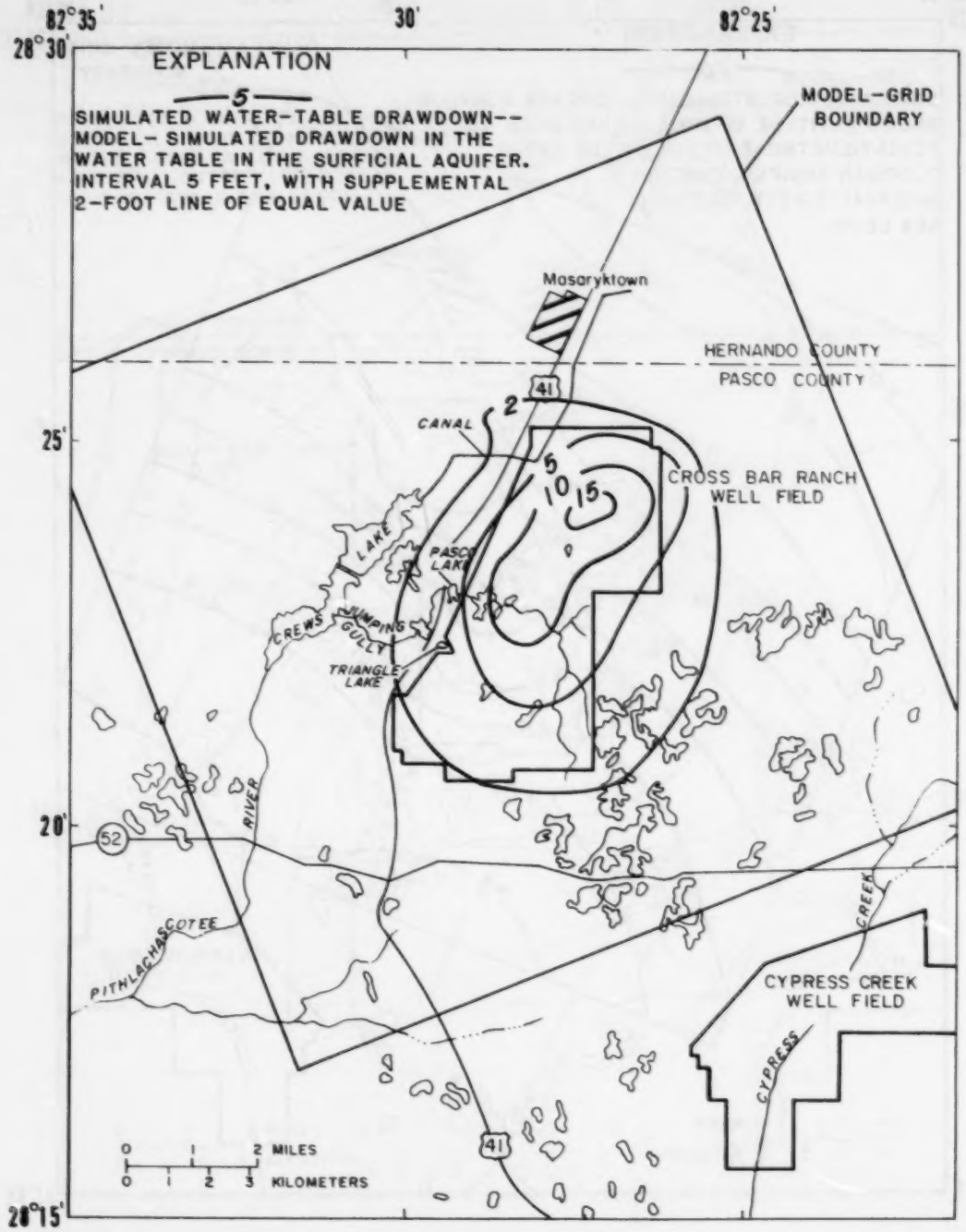

Figure 22.--Model-simulated drawdown in the water table in the surficial aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day.

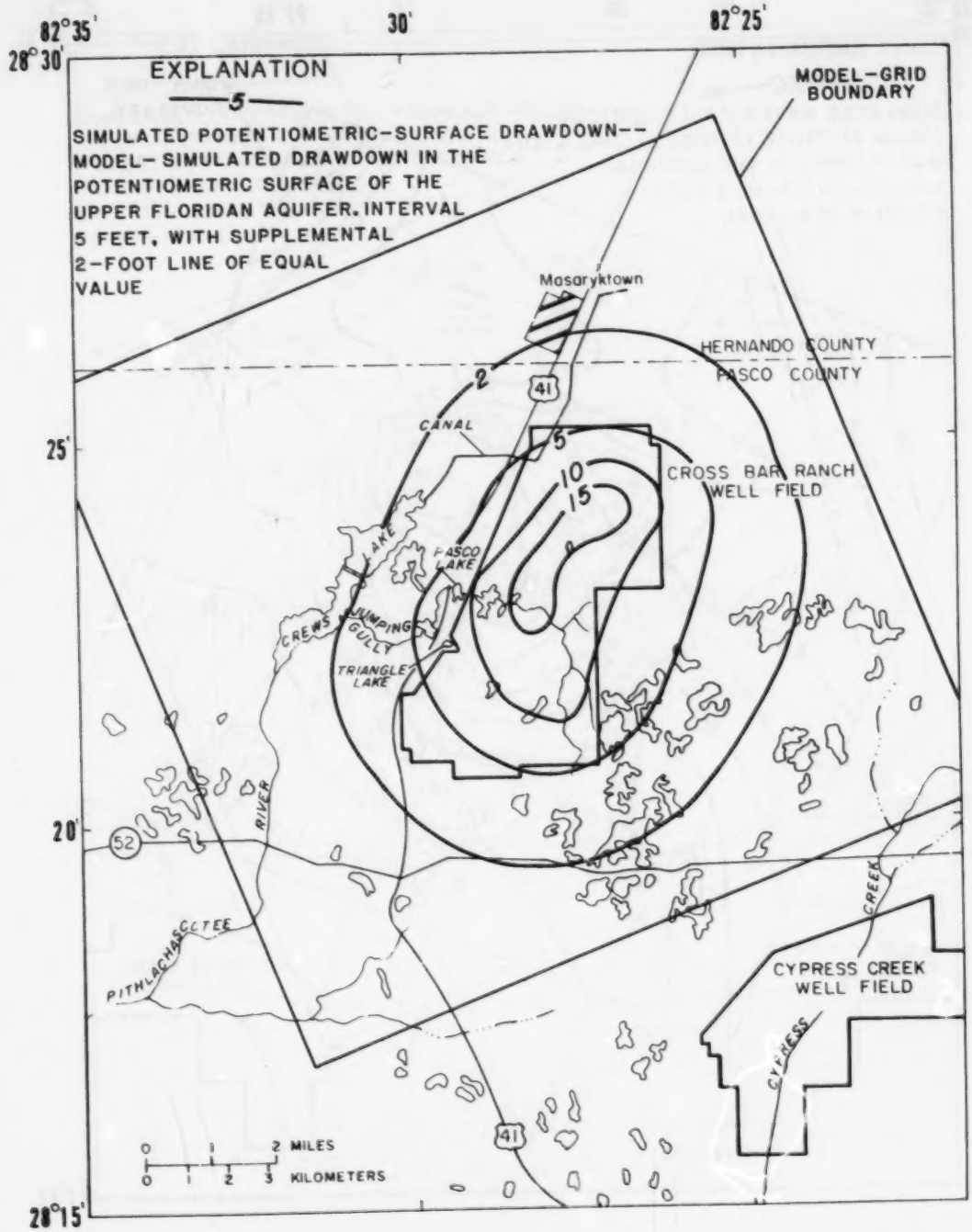

Figure 23.--Model-simulated drawdown in the potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 30 million gallons per day.

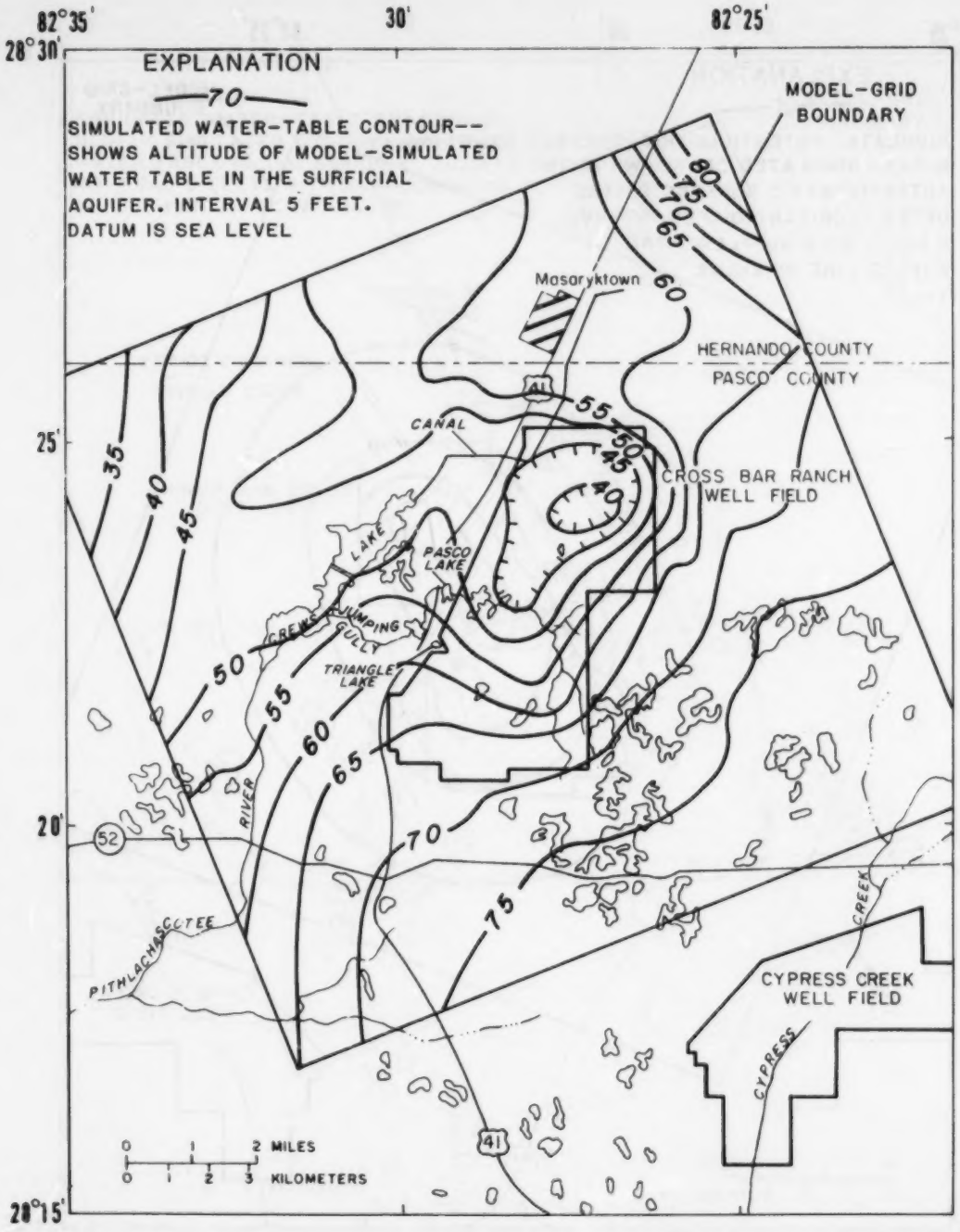

Figure 24.--Model-simulated water table in the surficial aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day.

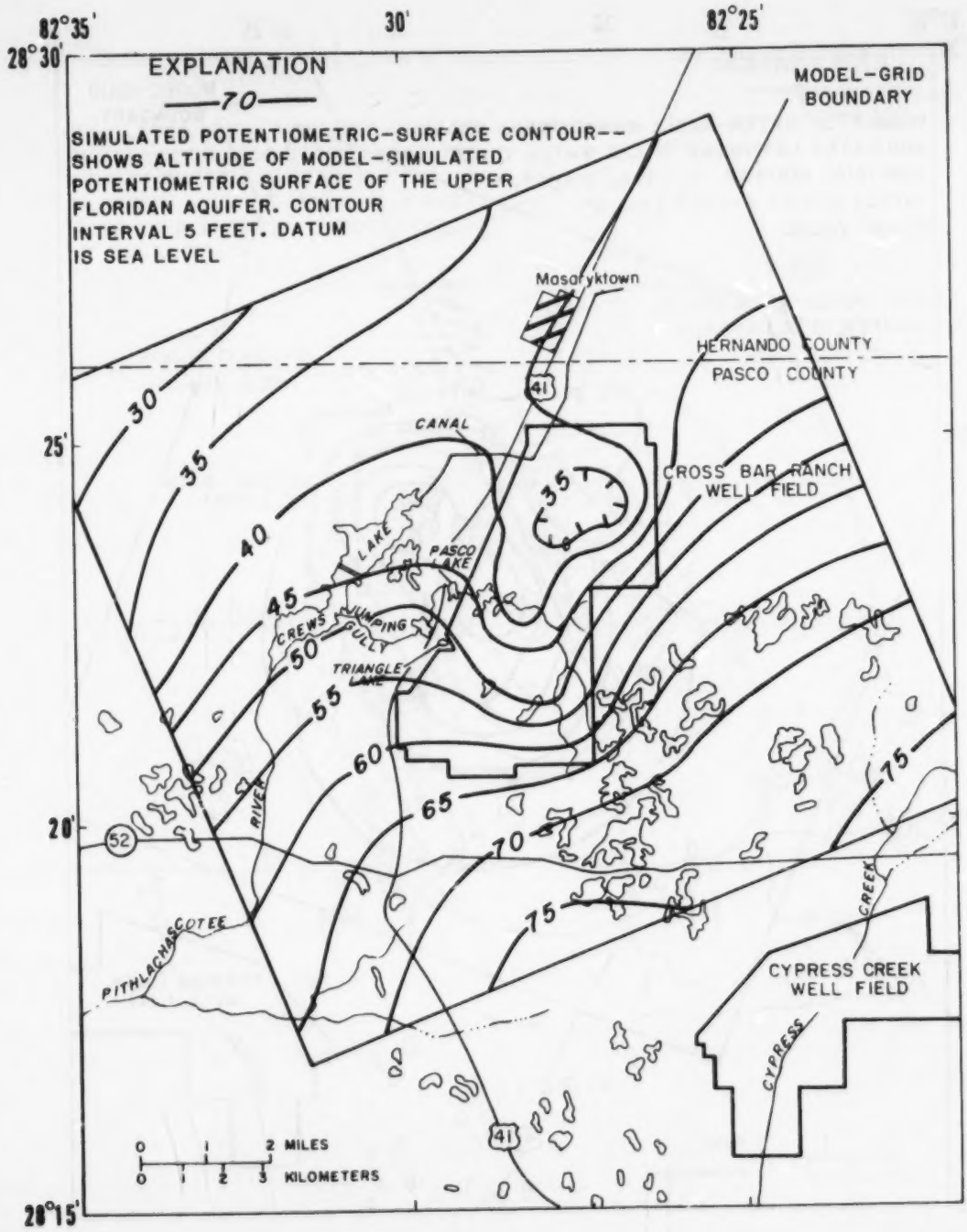

Figure 25.--Model-simulated potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day.

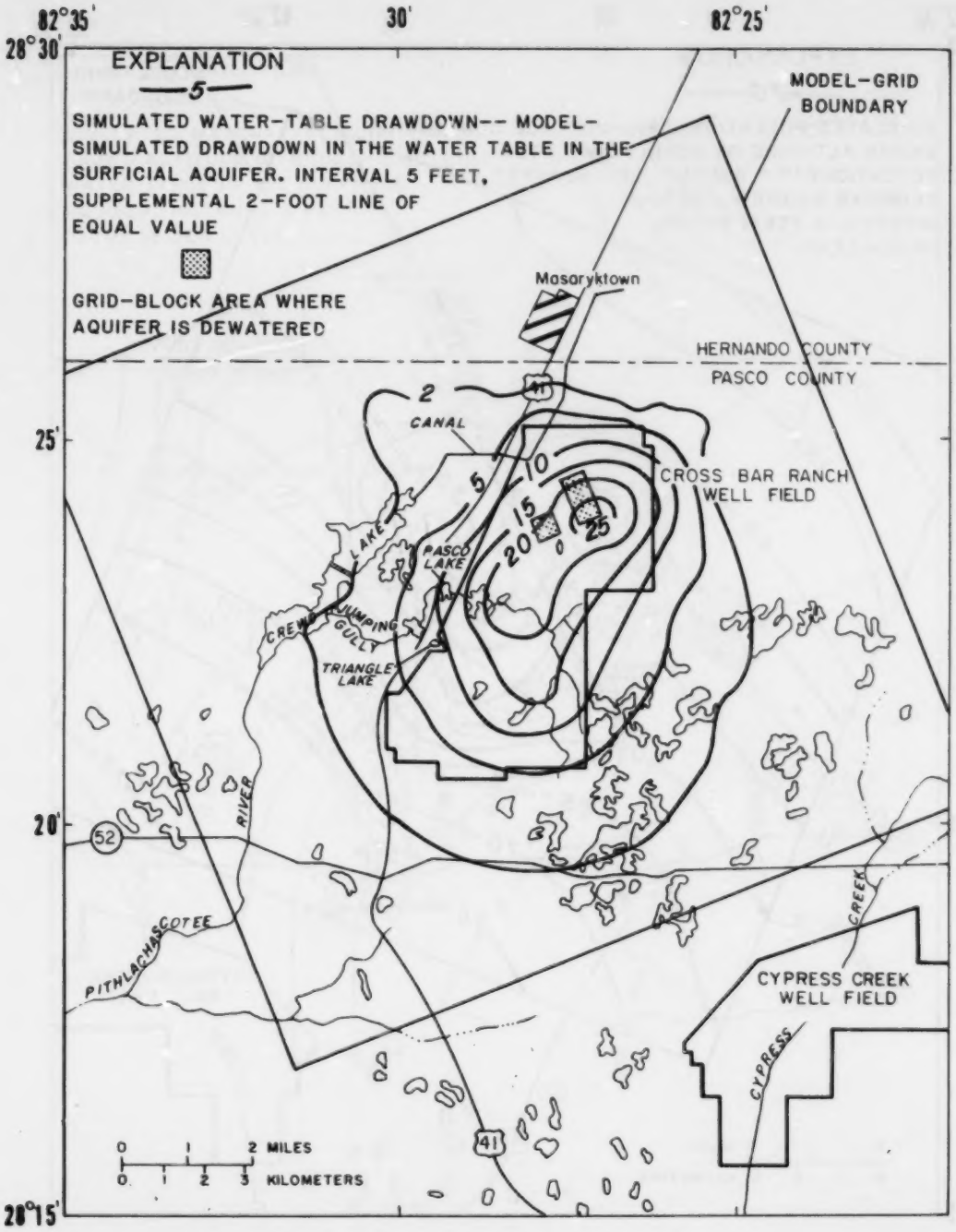

Figure 26.--Model-simulated drawdown in the water table in the surficial aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day.

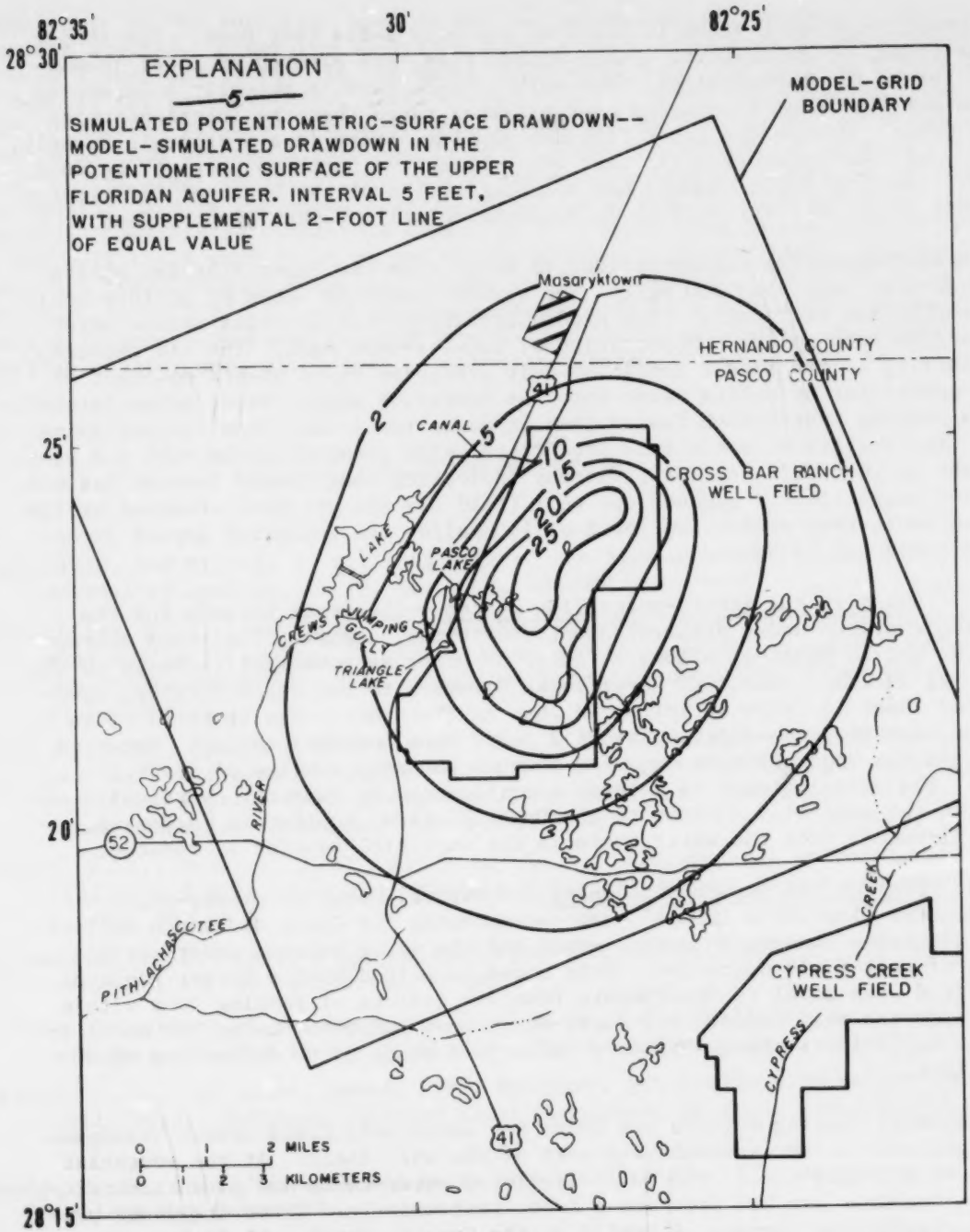

Figure 27.--Model-simulated drawdown in the potentiometric surface of the Upper Floridan aquifer with the Cross Bar Ranch well field pumping 45 million gallons per day.

of depression several miles in diameter but only a few feet deep. The shapes of the cones, or water-level trends within them, are altered by local inhomogeneities in the hydrogeologic framework. Pasco Lake is actually a dammed-up stream and its stage fluctuates over a larger range than the interconnecting water table. Within the Upper Floridan aquifer, there is a hydrologic anomaly, or zone of low transmissivity, that cuts across the northern part of the well field. The hydrologic anomaly has been delineated on the basis of differences in rates of water-level decline in observation wells during pumping tests.

Dissolved-solids concentrations in water from the Upper Floridan aquifer are generally less than 300 mg/L. The aquifer contains water of uniform quality areally and vertically. The middle confining unit contains saline water with a dissolved-solids concentration of about 19,000 mg/L. The low measured permeability of the middle confining unit precludes rapid upward movement of large quantities of saline water into the producing zone. Water moves laterally into a pumping center much faster than it moves vertically from the confining unit. The quality of water from production wells changed little with the pumping rate between 1978 and 1982, thereby indicating that upward leakage has not yet been significant. Because the well field has not yet been stressed at the maximum short-term production level of 45 Mgal/d, the potential impact of upconing could not be assessed.

2. Quantify the ground-water flow system.--The water balance for the hydrologic system under predevelopment conditions, assuming long-term average recharge and no pumping, allows 28 in/yr of water as potential recharge to the surficial aquifer. About 13 in/yr leaks downward to the Upper Floridan aquifer, and about 15 in/yr of inflow is lost as ET-runoff. The Upper Floridan aquifer receives, in addition, about 2 in/yr from boundary inflow. Water is lost from the Upper Floridan aquifer through boundary outflow of about 15 in/yr. The water balance is altered significantly by pumping. Vertical leakage from the surficial aquifer to the Upper Floridan aquifer is increased, while ET-runoff from the water table in the surficial aquifer is reduced.

3. Project the impact of pumping.--A digital model of steady-state ground-water flow for a 121-mi^2 area encompassing the Cross Bar Ranch well field simulates changes in water levels and the water balance under various levels of well-field operation. This model is alined with a larger regional well-field area model to incorporate boundary effects of pumping from within or outside the well field. For water-management purposes, using the model to predict water-level changes is more valid than using it to define new head conditions.

Regional pumping outside the Cross Bar Ranch well field causes drawdowns to be greatest in the southeastern part of the well field. At the southeast corner of the well field, the model-simulated water-table and potentiometric-surface declines are 0.6 foot and 1 foot, respectively. These drawdowns primarily result from pumping 30 Mgal/d at the Cypress Creek well field, about 5 miles southeast of Cross Bar Ranch.

The model was used to simulate the effects of pumping from the Upper Floridan aquifer at the Cross Bar Ranch well field at an average annual permitted rate of 30 Mgal/d and a maximum daily rate of 45 Mgal/d. The simulation runs produced maps showing cones of depression beneath the well field in the

water table in the surficial aquifer and the potentiometric surface of the Upper Floridan aquifer. Under the 30-Mgal/d pumping rate, simulated drawdown ranged between 5 feet and 17 feet in the water table over 8 mi^2 and between 5 feet and 21 feet in the potentiometric surface over 15 mi^2. Under the 45-Mgal/d pumping rate, simulated drawdown ranged between 5 feet and 26 feet in the water table over 16 mi^2 and between 5 feet and 35 feet in the potentiometric surface over 28 mi^2. The areal extent of the cone of depression approximately doubles when the pumping rate is increased from 30 Mgal/d to 45 Mgal/d. The surficial aquifer could possibly be completely dewatered in a small area in the northern part of the well field when it is pumped at the maximum permitted rate. Because lakes are hydraulically connected to the surficial aquifer, levels of lakes in and near the well field could decline substantially as a result of pumping. Pumping increases downward leakage from the surficial aquifer to the Upper Floridan aquifer and, ultimately, results in reduced ET and surface runoff.

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SUPPLEMENTAL DATA: MODELING PROCEDURES

A digital model can be used to simulate a hydrologic system and its response to hydrologic stresses, such as pumping or injection. A numerical solution using a finite-difference method is used to solve partial differential equations of ground-water flow. A digital model was selected over analytical techniques because of complexity of the hydrologic system at the Cross Bar Ranch well field. For example, complex patterns of pumping can be represented in a digital model, whereas it is cumbersome to represent more than two pumping centers analytically.

The three-dimensional ground-water flow model by Trescott (1975) and Trescott and Larson (1976), as modified by Hutchinson (1984a), was selected because: (1) the model has the ability to simulate hydrologic conditions in more than one aquifer; and (2) it allows for ET-runoff capture from the upper aquifer. The model is "quasi-three-dimensional" in that it computes two-dimensional (x,y) flow in two layers that are linked in the z dimension by leakage. Because the hydrologic system approaches an equilibrium condition within about 30 days after pumping begins at a constant rate, the system is considered to rapidly achieve a quasi-steady-state condition. Therefore, a steady-state model does not relate to a specific time period adequately and simply portrays the effects of most pumping scenarios.

Modeling procedures and their application to the Cross Bar Ranch well-field area are diagrammed in figure 28. The continuous aquifer region was discretized into a finite number of grid blocks, boundary conditions were established, and aquifer properties and ground-water withdrawal were estimated for each grid block. Input parameters were adjusted by trial and error within limits during model calibration until simulated heads under pumping conditions matched observed average heads measured in wells and lakes for September 1980 to May 1981. The model received additional validation when simulated heads under nonpumping conditions matched average heads for September 1976 to May 1977. Because the regional well-fields model (Hutchinson, 1984a) was based on this time period, it was also selected for the Cross Bar Ranch model validation. This allowed a check on the compatibility of the two models. Tests were made to assess the sensitivity of the model to extreme ranges in the input parameters. The model was then used to simulate response of the hydrologic system to various rates and distributions of pumping.

Model Grid

The continuous aquifer system was discretized by means of a finite-difference grid. The grid of 25 horizontal rows and 25 vertical columns was centered over the Cross Bar Ranch well field. The first and last row and column form the border and are required to be inactive by the model. This results in a 23 by 23 active grid that encompasses the 121-mi^2 area (fig. 29). Grid size is variable, with dimensions of individual blocks ranging from 5,280 feet by 5,280 feet at the corners of the model to 1,760 feet by 1,760 feet within the well field. At the center of each grid block is a node for which data are input to and output from the model.

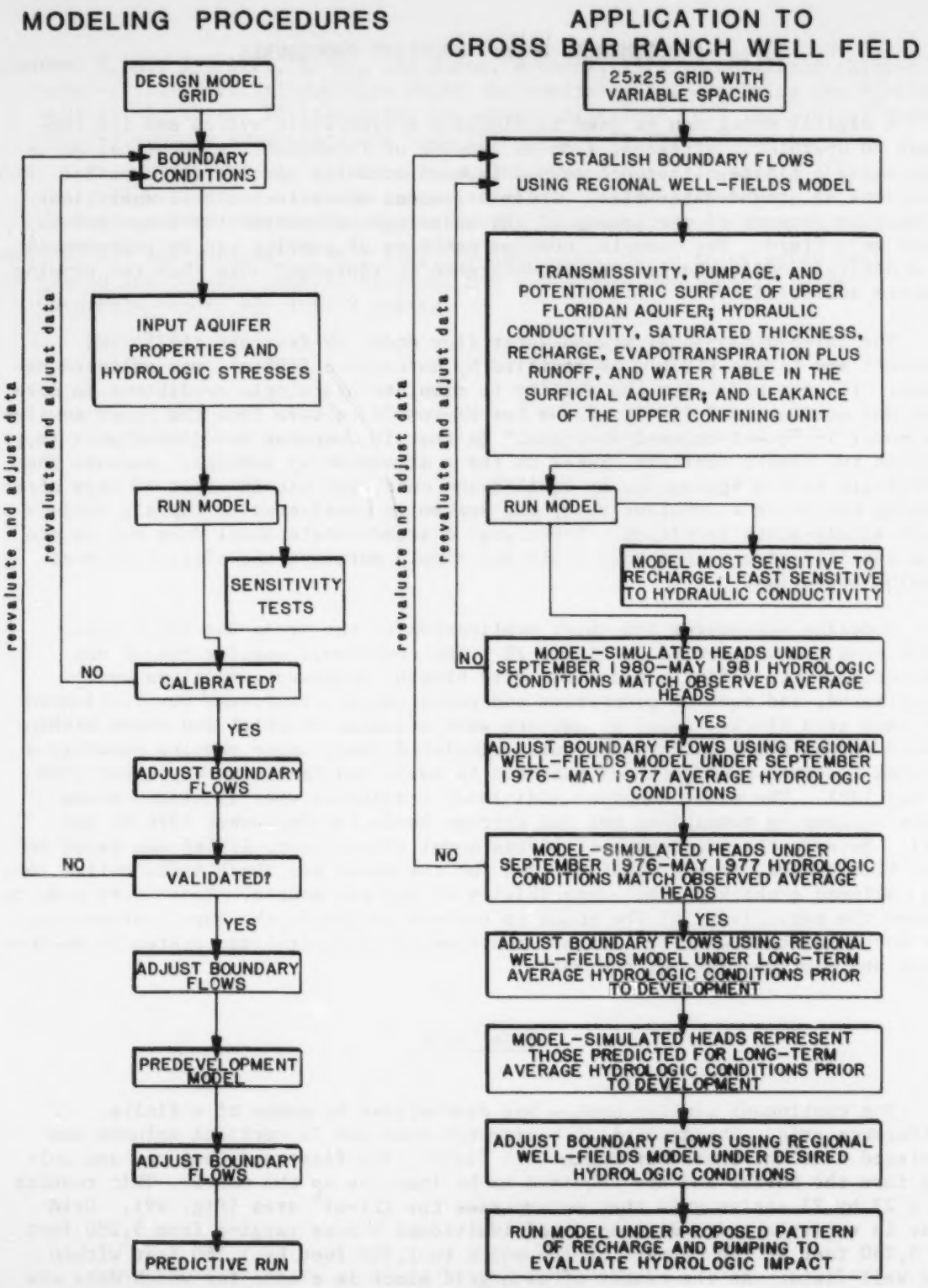
MODELING PROCEDURES
DESIGN MODEL GRID
BOUNDARY CONDITIONS
INPUT AQUIFER PROPERTIES AND HYDROLOGIC STRESSES
RUN MODEL
SENSITIVITY TESTS
CALIBRATED?
NO
YES
ADJUST BOUNDARY FLOWS
VALIDATED?
NO
YES
ADJUST BOUNDARY FLOWS
PREDEVELOPMENT MODEL
ADJUST BOUNDARY FLOWS
PREDICTIVE RUN
reevaluate and adjust data
reevaluate and adjust data
APPLICATION TO CROSS BAR RANCH WELL FIELD
25x25 GRID WITH VARIABLE SPACING
ESTABLISH BOUNDARY FLOWS USING REGIONAL WELL-FIELDS MODEL
TRANSMISSIVITY, PUMPAGE, AND POTENTIOMETRIC SURFACE OF UPPER FLORIDAN AQUIFER; HYDRAULIC CONDUCTIVITY, SATURATED THICKNESS, RECHARGE, EVAPOTRANSPIRATION PLUS RUNOFF, AND WATER TABLE IN THE SURFICIAL AQUIFER; AND LEAKANCE OF THE UPPER CONFINING UNIT
RUN MODEL
MODEL MOST SENSITIVE TO RECHARGE, LEAST SENSITIVE TO HYDRAULIC CONDUCTIVITY
MODEL-SIMULATED HEADS UNDER SEPTEMBER 1980-MAY 1981 HYDROLOGIC CONDITIONS MATCH OBSERVED AVERAGE HEADS
NO
YES
ADJUST BOUNDARY FLOWS USING REGIONAL WELL-FIELDS MODEL UNDER SEPTEMBER 1976- MAY 1977 AVERAGE HYDROLOGIC CONDITIONS
MODEL-SIMULATED HEADS UNDER SEPTEMBER 1976-MAY 1977 HYDROLOGIC CONDITIONS MATCH OBSERVED AVERAGE HEADS
NO
YES
ADJUST BOUNDARY FLOWS USING REGIONAL WELL-FIELDS MODEL UNDER LONG-TERM AVERAGE HYDROLOGIC CONDITIONS PRIOR TO DEVELOPMENT
MODEL-SIMULATED HEADS REPRESENT THOSE PREDICTED FOR LONG-TERM AVERAGE HYDROLOGIC CONDITIONS PRIOR TO DEVELOPMENT
ADJUST BOUNDARY FLOWS USING REGIONAL WELL-FIELDS MODEL UNDER DESIRED HYDROLOGIC CONDITIONS
RUN MODEL UNDER PROPOSED PATTERN OF RECHARGE AND PUMPING TO EVALUATE HYDROLOGIC IMPACT
reevaluate and adjust data
reevaluate and adjust data

Figure 28.--Modeling procedures.

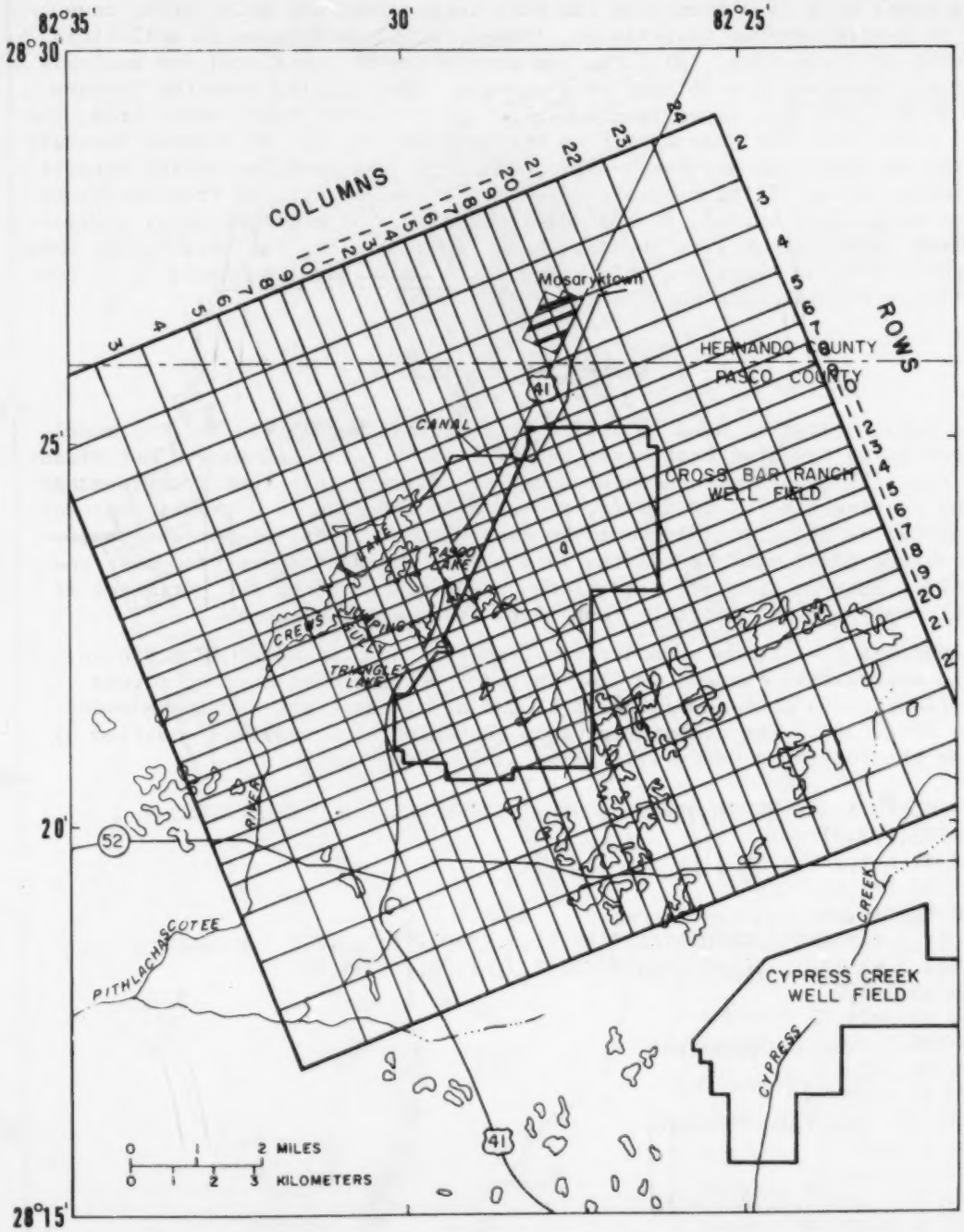

Figure 29.--Model grid encompassing the Cross Bar Ranch well field.

The model grid is alined with the much larger regional model grid, consisting of 1-mile squares (Hutchinson, 1984a), that encompasses 10 well-field areas north of Tampa (fig. 30). The two models can be interfaced for analysis of special ground-water problems. For example, when pumping from the Cypress Creek well field lowers water levels within the Cross Bar Ranch model area, the regional model with the same specified stresses can be used to provide boundary conditions in the Cross Bar Ranch model, which is then used for making detailed predictions. Also, if the cone of depression caused by pumping from the Cross Bar Ranch well field extends to the model boundary, the regional model can likewise be run to obtain correct boundary heads and flows for the small-scale model. The compatibility of the two models allowed the Cross Bar Ranch grid to be compact, thereby facilitating calibration of the model.

Boundary Conditions

The major criterion used to define hypothetical boundaries for the model was to determine the area that might be affected by future pumping. Hutchinson (1984a, fig. 25) used a ground-water model to estimate that, under the average permitted pumping rate of 30 Mgal/d, the area of the cone of depression around the Cross Bar Ranch well field would be about 140 mi^2. Based upon this estimate, a square model with boundaries 13 miles on a side was centered over the well field. Because inactive grid blocks are required along the perimeter of the model, only 121 mi^2 actively respond to hydrologic stresses.

Volumetric flow rates were derived from the regional model (Hutchinson, 1984a) to approximate changes in flow in the Upper Floridan aquifer across 44 grid-block faces that abut 88 grid blocks along the Cross Bar Ranch model boundary (fig. 30). The computer program (Hutchinson, 1984a) was modified by inserting the following cards after line 13070:

```
C     ---COMPUTE AND PUNCH BNDRY FLOWS AT CROSS BAR RANCH WELL FIELD---
      WRITE(7,349)
      DO 31 K=1,1
      DO 32 I=1,I1
      DO 32 J=1,J1
      TC(I,J,K)=TC(I,J,K)*DELY(I)*(PHI(I,J,K)-PHI(I+1,J,K))
   32 TR(I,J,K)=TR(I,J,K)*DELX(J)*(PHI(I,J,K)-PHI(I,J+1,K))
      DO 33 I=2,2
      DO 33 J=21,31
   33 WRITE(7,305)I,J,TC(I,J,K)
      DO 34 I=3,13
      DO 34 J=20,20
   34 WRITE(7,305)I,J,TR(I,J,K)
      DO 35 I=3,13
      DO 35 J=31,31
   35 WRITE(7,305)I,J,TR(I,J,K)
      DO 36 I=13,13
      DO 36 J=21,31
   36 WRITE(7,305)I,J,TC(I,J,K)
   31 CONTINUE
      IF (NCH.EQ.0) GO TO 250
      WRITE(6,270)
      WRITE(6,280) ((JFLO(I,J),J=1,3),FLOW(I),I=1,NCH)
  250 CONTINUE
```

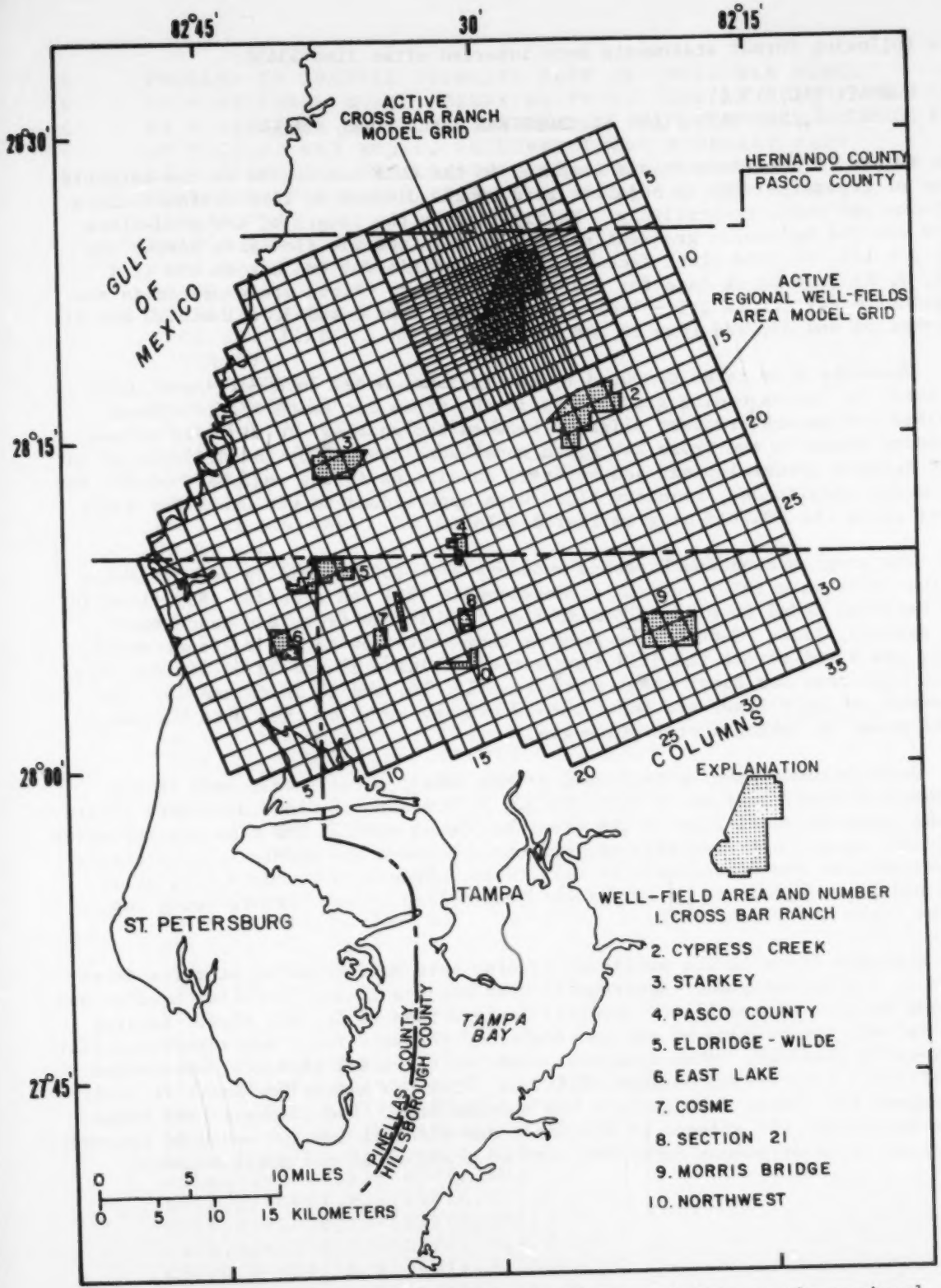

Figure 30.--Cross Bar Ranch model grid and its relation to the regional well-fields area model grid.

The following format statements were inserted after line 13430:

```
305 FORMAT(2I10,E15.5)
349 FORMAT(5X,'BOUNDARY FLOWS AT CROSS BAR RANCH MODEL FOLLOW')
```

The TR and TC coefficients are computed in the COEF subroutine as the harmonic mean of transmissivity in adjacent grid blocks divided by flow distance along columns and rows, respectively. Multiplying by the length of the grid-block face and the hydraulic gradient results in a volumetric flow rate across the (I, J + 1/2, K) grid-block face for the TR coefficient and across the (I + 1/2, J, K) grid-block face for the TC coefficient. Flows are computed in the regional model across grid-block faces between rows 2 and 3, columns 20 and 21, columns 31 and 32, and rows 13 and 14 (fig. 30).

Boundary flow rates computed by the regional model were not apportioned directly to corresponding grid blocks in the Cross Bar Ranch model because calibration parameters vary slightly between the models. To minimize errors, boundary flows in the Cross Bar Ranch model were changed by the differences in flow between predevelopment and stressed conditions in the regional model. For the model predictions, boundary flows were apportioned to the Cross Bar Ranch model using the FORTRAN program listed below.

The program computes stressed boundary flow (CS) by adding some fraction of the difference (DIF) between predevelopment (RP) and stressed (RS) flows in the regional model to predevelopment flow (CP) in the Cross Bar Ranch model. For example, lines 78-80 of the program show that flow in the regional model along row 9 and across the grid face between columns 31 and 32 is divided equally in the Cross Bar Ranch model among rows 15, 16, and 17 in column 24. The adjusted boundary flows are input to the pumping array of the Cross Bar Ranch model prior to making a predictive run.

Under various pumping test runs of the model, water levels rose in the northwest corner, indicating that changes in boundary outflow there were greater in the regional model than in the Cross Bar Ranch model. The flow discrepancies were attributed to transmissivity variations between the models. To partially compensate for the transmissivity variations, changes in boundary flow at 11 grid blocks were reduced by 10 percent (multiplied by 0.9) before being input to the Cross Bar Ranch model.

Boundary flows in the surficial aquifer were held constant at rates determined in the calibration. Apparently, head changes in the surficial aquifer are related more to ET-runoff and vertical leakage than to lateral flow. Lateral flow is very low because of the aquifer's low transmissivity and relatively flat water-table gradient. When drawdown occurs at the model boundary, worst-case conditions are portrayed because additional flow (no matter how small it really is) cannot be induced from outside the modeled area. Had constant-head boundaries been used, the effects of ET-runoff and vertical leakage would be ignored, resulting in an erroneous condition with no drawdown at the model boundary.

```
C      PROGRAM TO COMPUTE BOUNDARY FLOW IN CROSS BAR MODEL
C      RP = REGIONAL MODEL, PREDEVELOPMENT FLOW AT GRID FACE
C      RS = REGIONAL MODEL, STRESSED FLOW AT GRID FACE
C      CP = CROSS BAR MODEL, PREDEVELOPMENT BOUNDARY FLOW
C      CS = CROSS BAR MODEL, STRESSED FLOW AT BOUNDARY
       DIMENSION RS(34,36),RP(34,36),CP(24,24),CS(24,24),
      1DIF(34,36)
   10  READ(5,100)I,J,RS(I,J)
       IF(I.EQ.13.AND.J.EQ.31) GO TO 20
       GO TO 10
   20  READ(5,100)I,J,RP(I,J)
       IF(I.EQ.13.AND.J.EQ.31) GO TO 30
       GO TO 20
   30  DO 40 I=2,13
       DO 40 J=20,31
       IF (RP(I,J).EQ.0..OR.RS(I,J).EQ.0.) GO TO 40
       DIF(I,J)=RP(I,J)-RS(I,J)
   40  CONTINUE
       READ(5,200)I,J,CP(I,J)
       IF(I.EQ.24.AND.J.EQ.24) GO TO 50
       GO TO 40
   50  CS(2,2)=CP(2,2)+.9*(DIF(2,21)+DIF(3,20))
       CS(2,3)=CP(2,3)+(.9*DIF(2,22))
       CS(2,4)=CP(2,4)+(.9*(DIF(2,23)/2.))
       CS(2,5)=CP(2,5)+(.9*(DIF(2,23)/2.))
       CS(2,6)=CP(2,6)+(.9*(DIF(2,24)/3.))
       CS(2,7)=CP(2,7)+(.9*(DIF(2,24)/3.))
       CS(2,8)=CP(2,8)+(.9*(DIF(2,24)/3.))
       CS(2,9)=CP(2,9)+(.9*(DIF(2,25)/3.))
       CS(2,10)=CP(2,10)+(.9*(DIF(2,25)/3.))
       CS(2,11)=CP(2,11)+(.9*(DIF(2,25)/3.))
       CS(2,12)=CP(2,12)+(DIF(2,26)/3.)
       CS(2,13)=CP(2,13)+(DIF(2,26)/3.)
       CS(2,14)=CP(2,14)+(DIF(2,26)/3.)
       CS(2,15)=CP(2,15)+(DIF(2,27)/3.)
       CS(2,16)=CP(2,16)+(DIF(2,27)/3.)
       CS(2,17)=CP(2,17)+(DIF(2,27)/3.)
       CS(2,18)=CP(2,18)+(DIF(2,28)/3.)
       CS(2,19)=CP(2,19)+(DIF(2,28)/3.)
       CS(2,20)=CP(2,20)+(DIF(2,28)/3.)
       CS(2,21)=CP(2,21)+(DIF(2,29)/2.)
       CS(2,22)=CP(2,22)+(DIF(2,29)/2.)
       CS(2,23)=CP(2,23)+DIF(2,30)
       CS(2,24)=CP(2,24)+DIF(2,31)-DIF(3,31)
       CS(3,2)=CP(3,2)+(.9*DIF(4,20))
       CS(4,2)=CP(4,2)+(.9*(DIF(5,20)/2.))
       CS(5,2)=CP(5,2)+(.9*(DIF(5,20)/2.))
       CS(6,2)=CP(6,2)+(DIF(6,20)/3.)
       CS(7,2)=CP(7,2)+(DIF(6,20)/3.)
       CS(8,2)=CP(8,2)+(DIF(6,20)/3.)
       CS(9,2)=CP(9,2)+(DIF(7,20)/3.)
       CS(10,2)=CP(10,2)+(DIF(7,20)/3.)
       CS(11,2)=CP(11,2)+(DIF(7,20)/3.)
       CS(12,2)=CP(12,2)+(DIF(8,20)/3.)
```

```
CS(13,2)=CP(13,2)+(DIF(8,20)/3.)
CS(14,2)=CP(14,2)+(DIF(8,20)/3.)
CS(15,2)=CP(15,2)+(DIF(9,20)/3.)
CS(16,2)=CP(16,2)+(DIF(9,20)/3.)
CS(17,2)=CP(17,2)+(DIF(9,20)/3.)
CS(18,2)=CP(18,2)+(DIF(10,20)/3.)
CS(19,2)=CP(19,2)+(DIF(10,20)/3.)
CS(20,2)=CP(20,2)+(DIF(10,20)/3.)
CS(21,2)=CP(21,2)+(DIF(11,20)/2.)
CS(22,2)=CP(22,2)+(DIF(11,20)/2.)
CS(23,2)=CP(23,2)+DIF(12,20)
CS(3,24)=CP(3,24)-DIF(4,31)
CS(4,24)=CP(4,24)-(DIF(5,31)/2.)
CS(5,24)=CP(5,24)-(DIF(5,31)/2.)
CS(6,24)=CP(6,24)-(DIF(6,31)/3.)
CS(7,24)=CP(7,24)-(DIF(6,31)/3.)
CS(8,24)=CP(8,24)-(DIF(6,31)/3.)
CS(9,24)=CP(9,24)-(DIF(7,31)/3.)
CS(10,24)=CP(10,24)-(DIF(7,31)/3.)
CS(11,24)=CP(11,24)-(DIF(7,31)/3.)
CS(12,24)=CP(12,24)-(DIF(8,31)/3.)
CS(13,24)=CP(13,24)-(DIF(8,31)/3.)
CS(14,24)=CP(14,24)-(DIF(8,31)/3.)
CS(15,24)=CP(15,24)-(DIF(9,31)/3.)
CS(16,24)=CP(16,24)-(DIF(9,31)/3.)
CS(17,24)=CP(17,24)-(DIF(9,31)/3.)
CS(18,24)=CP(18,24)-(DIF(10,31)/3.)
CS(19,24)=CP(19,24)-(DIF(10,31)/3.)
CS(20,24)=CP(20,24)-(DIF(10,31)/3.)
CS(21,24)=CP(21,24)-(DIF(11,31)/2.)
CS(22,24)=CP(22,24)-(DIF(11,31)/2.)
CS(23,24)=CP(23,24)-DIF(12,31)
CS(24,2)=CP(24,2)-DIF(13,21)+DIF(13,20)
CS(24,3)=CP(24,3)-DIF(13,22)
CS(24,4)=CP(24,4)-(DIF(13,23)/2.)
CS(24,5)=CP(24,5)-(DIF(13,23)/2.)
CS(24,6)=CP(24,6)-(DIF(13,24)/3.)
CS(24,7)=CP(24,7)-(DIF(13,24)/3.)
CS(24,8)=CP(24,8)-(DIF(13,24)/3.)
CS(24,9)=CP(24,9)-(DIF(13,25)/3.)
CS(24,10)=CP(24,10)-(DIF(13,25)/3.)
CS(24,11)=CP(24,11)-(DIF(13,25)/3.)
CS(24,12)=CP(24,12)-(DIF(13,26)/3.)
CS(24,13)=CP(24,13)-(DIF(13,26)/3.)
CS(24,14)=CP(24,14)-(DIF(13,26)/3.)
CS(24,15)=CP(24,15)-(DIF(13,27)/3.)
CS(24,16)=CP(24,16)-(DIF(13,27)/3.)
CS(24,17)=CP(24,17)-(DIF(13,27)/3.)
CS(24,18)=CP(24,18)-(DIF(13,28)/3.)
CS(24,19)=CP(24,19)-(DIF(13,28)/3.)
CS(24,20)=CP(24,20)-(DIF(13,28)/3.)
CS(24,21)=CP(24,21)-(DIF(13,29)/2.)
CS(24,22)=CP(24,22)-(DIF(13,29)/2.)
CS(24,23)=CP(24,23)-DIF(13,30)
CS(24,24)=CP(24,24)-DIF(13,31)
```

```
      DO 60 I=2,24
      DO 60 J=2,26
      IF (CS(I,J).EQ.0.0) GO TO 60
      WRITE(6,300)I,J,CS(I,J)
   60 CONTINUE
  100 FORMAT(2I10,E15.5)
  200 FORMAT(10X,2I10,F10.0)
  300 FORMAT(9X,'1',2I10,F10.2)
      STOP
      END
```

Input Parameters

The steady-state model requires input parameters for each grid block including:

1. Altitude of the observed potentiometric surface of the Upper Floridan aquifer;
2. Altitude of the observed water table in the surficial aquifer;
3. Storage coefficient of the Upper Floridan aquifer (defined as zero);
4. Storage coefficient (defined as zero) and constant-head nodes of the surficial aquifer;
5. Transmissivity of the Upper Floridan aquifer;
6. Leakance of the upper confining unit;
7. Hydraulic conductivity of the surficial aquifer;
8. Altitude of the bottom of the surficial aquifer;
9. Recharge rate to the surficial aquifer;
10. Maximum ET-runoff capture rate from the water table divided by maximum depth at which ET-runoff capture occurs;
11. Altitude of the bottom of the zone in which ET-runoff occurs;
12. Altitude of land surface;
13. Model-grid spacing; and
14. Pumping rate from the Upper Floridan aquifer and cross-boundary flow.

The model utilizes many input parameters directly in ground-water flow equations. Others are used indirectly to compute parameters that vary with head, such as transmissivity of the surficial aquifer or ET-runoff capture rate. Ranges for hydrologic input parameters for the steady-state calibration are presented in table 6. The parameter values were based on analyses of aquifer tests (fig. 5) and on preliminary estimates derived from the regional well-fields model (Hutchinson, 1984a).

Table 6.--Values for hydrologic parameters of the calibrated steady-state model

Parameter	Value	Source of data
Potentiometric-surface altitude	23-74 ft	Ryder and Mills (1977a; 1977b).
Water-table altitude	27-76 ft	Ryder and Mills (1977a; 1977b).
Storage coefficient, both aquifers	0	----
Transmissivity of Upper Floridan aquifer	6,600-221,000 ft^2/d	Published aquifer-test results and model calibration (Leggette, Brashears, and Graham, Inc., 1978).
Transmissivity of surficial aquifer	54-324 ft^2/d	Model computed, based on hydraulic conductivity measurements of Sinclair (1974).
Leakance	0.0002-0.0009 (ft/d)/ft	Published aquifer-test results and model calibration (Leggette, Brashears, and Graham, Inc., 1978).
Hydraulic conductivity of surficial aquifer	10 ft/d	Sinclair (1974).
Altitude of the bottom of surficial aquifer	-1 -(+65) ft	Wolansky and others (1979).
Saturated thickness of surficial aquifer	5.4-32.4 ft	Model computed, based on difference between water table and estimated bottom of aquifer.
Recharge rate to surficial aquifer	20 in/yr	Estimated by summing leakage and ET-runoff from water table.
Surficial aquifer boundary flow	0-0.60 ft^3/s in	Derived during calibration.
Upper Floridan aquifer boundary flow	1.0 ft^3/s in -5.6 ft^3/s out	Based on regional model.
ET-runoff rate from water table	0-24 in/yr	Model computed.
Altitude of land surface	34-100 ft	USGS topographic maps.
Pumping rate from Upper Floridan aquifer at individual nodes	2,290,000 gal/d	SWFWMD water-use permits, pumping reports, and irrigation requirements.
Total pumping rate from Upper Floridan aquifer	12,800,000 gal/d	----

Potentiometric surface: Water levels in the lower layer (Upper Floridan aquifer) were obtained by overlaying the model grid upon maps of the average potentiometric surface under nonpumping and pumping conditions (figs. 9 and 11). Average water levels were assigned to each grid block, resulting in an array of starting heads for input to layer 1 of the model for each condition.

Water table: Water levels in the upper layer (surficial aquifer) were obtained by overlaying the model grid upon maps of the average water table under nonpumping and pumping conditions (figs. 8 and 10). Average water levels were assigned to each grid block, resulting in an array of starting heads for input to layer 2 of the model for each condition.

Storage coefficient: The storage coefficient was set at zero. Because the model represents steady-state, or stabilized aquifer conditions, inflows and outflows balance, and there is no change in ground-water storage. Setting the storage coefficient matrices to zero in the model is for computational efficiency so that steady state can be reached in one time step.

The storage coefficient matrix is also used to assign constant-head values to selected grid blocks. For the calibration and validation runs, known heads were simulated by the model; therefore, constant-head grid blocks were designated at the perimeter of the model.

Transmissivity of the Upper Floridan aquifer: Transmissivity of the Upper Floridan aquifer increases gradationally from south to north from about 28,000 ft^2/d to 221,000 ft^2/d (fig. 31). Based on pumping tests, the transmissivity of a 400-foot wide zone corresponding to the hydrologic anomaly was computed to be 2,000 ft^2/d (Leggette, Brashears, and Graham, Inc., 1979d). In the center of the model, the hydrologic anomaly was defined by a low transmissivity of 6,600 ft^2/d based on a grid-block width of 1,760 feet.

Leakance: Leakance is the modeling mechanism that allows vertical flow between the surficial and Upper Floridan aquifers. Leakance is the vertical hydraulic conductivity of the upper confining unit divided by its thickness. Estimates of leakance were distributed in the model by relating values derived from pumping tests in the well field (fig. 5) to confining bed thickness and head difference between the water table and potentiometric surface. Leakance, as shown in figure 32, is lowest in the area of the Brooksville Ridge physiographic unit (fig. 2) where the confining unit is known to be thick (Buono and others, 1979) and the head difference is great. Leakance is highest in the Lakes Terrace physiographic unit where the confining unit has been breached by sinkholes and there is a small head difference. Figure 33 depicts leakage rates as derived in the model that simulates predevelopment conditions. Leakage is upward in the area of the Pithlachascotee River. Elsewhere, leakage is downward from the surficial to the Upper Floridan aquifer.

Hydraulic conductivity of the surficial aquifer: Hydraulic conductivity of the surficial aquifer was estimated at a uniform 10 ft/d. This estimate is based on laboratory measurements for surficial materials in northwest Hillsborough County (Sinclair, 1974). The model computes transmissivity of the surficial aquifer by multiplying hydraulic conductivity by saturated thickness, determined as the difference between the simulated water table and the bottom of the surficial aquifer. For the calibration, transmissivity of the surficial aquifer ranged from 54 ft^2/d to 324 ft^2/d.

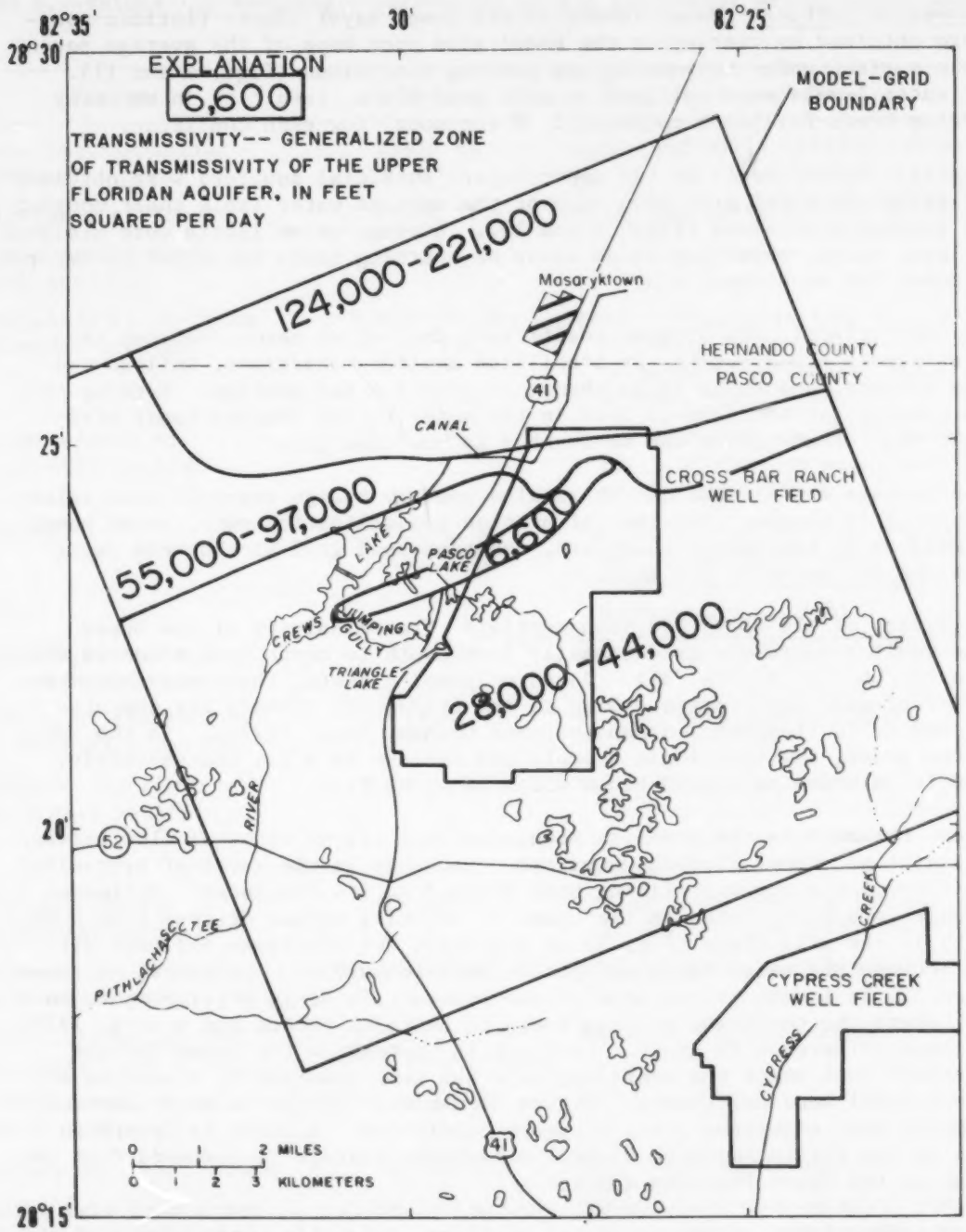

Figure 31.--Transmissivity of the Upper Floridan aquifer.

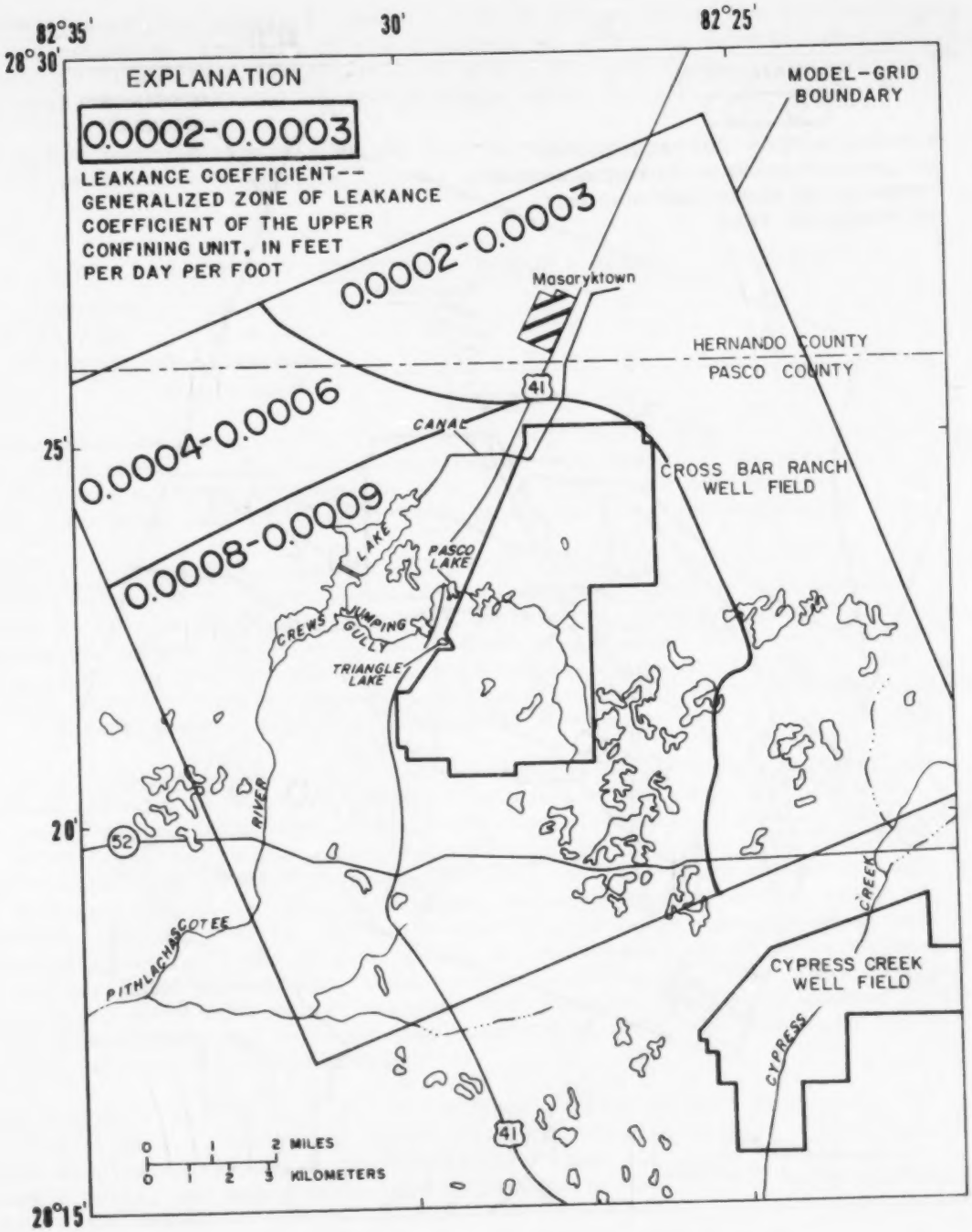

Figure 32.--Leakance of the upper confining unit.

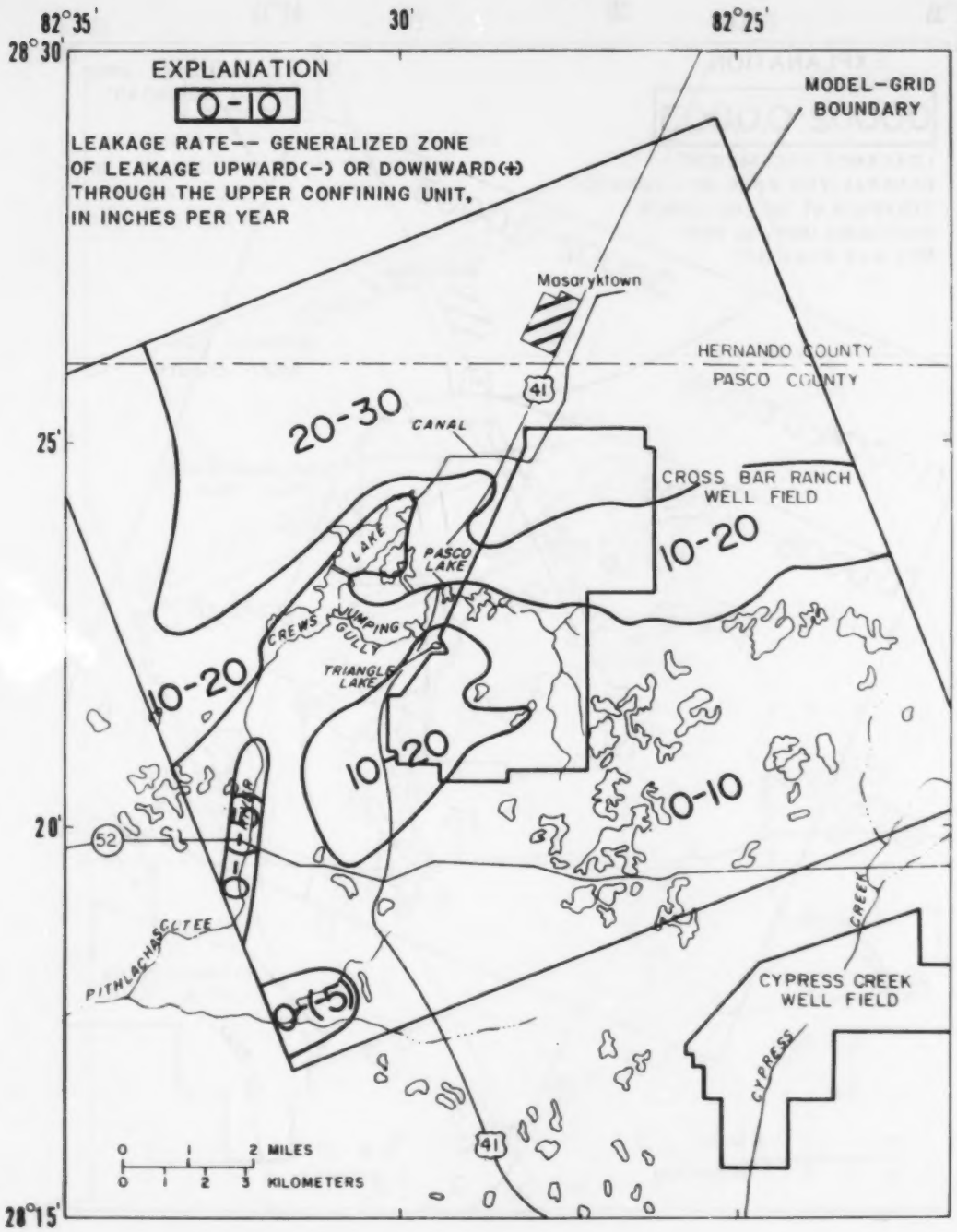

Figure 33.--Leakage rates through the upper confining unit for predevelopment conditions.

Bottom of surficial aquifer: The altitude of the bottom of the surficial aquifer was estimated from maps of the thickness of surficial deposits (Wolansky and others, 1979) and from lithologic logs within the well field. The saturated thickness of the surficial aquifer averages about 20 feet.

Recharge: Recharge conditions vary for the calibration, validation, and predictive phases of the modeling process and were computed as follows:

PHASE	RAINFALL	-	[MINIMUM EVAPOTRANSPIRATION	+	RUNOFF]	=	RECHARGE
CALIBRATION	45	- [	25	+	0]	=	20
VALIDATION	51.6	- [	25	+	1.6]	=	25
PREDICTION	55	- [	25	+	2]	=	28

Actual measurements of rainfall and runoff were used for the calibration and validation phases. Long-term average values were used for the prediction phase. Rainfall was measured at Chinsegut Hill, and runoff was measured at Jumping Gully. Recharge was estimated to be constant over the entire modeled area.

ET-runoff capture rate: Capture of ET from the water table and runoff was considered to be the variable source from which pumped water is derived since recharge is held constant in the model. Under normal climatological conditions, pumping will lower the water table, thereby creating the potential for extra recharge during the wet season and, subsequently, less runoff. Thus, the modeled ET-runoff capture parameter not only represents ET from the water table, but also represents changes in recharge and runoff.

ET-runoff capture depth: Capture of ET from the water table and runoff was assumed to occur in the zone between land surface and a depth of 10 feet. The ET-runoff capture rate derived in the conceptual model is that for each foot of water-table decline, 3.8 in/yr of water can be captured. The potential ET-runoff rate from the water table is 38 in/yr in areas where the water table is at land surface and zero where the water table is 10 feet or more below land surface. The regional pattern of ET-runoff for average predevelopment conditions is shown in figure 34. It should be emphasized that ET is from the water in the surficial aquifer and, thus, is only a component of the total ET found in standard hydrologic budget analyses (for example, Cherry and others, 1970). ET from water and land surfaces, the unsaturated zone, and from flood runoff are not represented in the model.

Land surface: The average altitude of land surface in each grid block was obtained from U.S. Geological Survey 1:24,000 topographic maps. Topographic highs usually correspond to the Brooksville Ridge and Lakes Terrace physiographic units, and topographic lows correspond to the Central Swamp and Lowlands Plain units.

Pumpage: Average withdrawals from the Upper Floridan aquifer for the period from September 1980 to May 1981 were estimated from records of the Southwest Florida Water Management District and the West Coast Regional Water Supply Authority. Pumping for municipal supply from the well field during this period averaged 12.8 Mgal/d and was distributed among pumping wells in figure 11

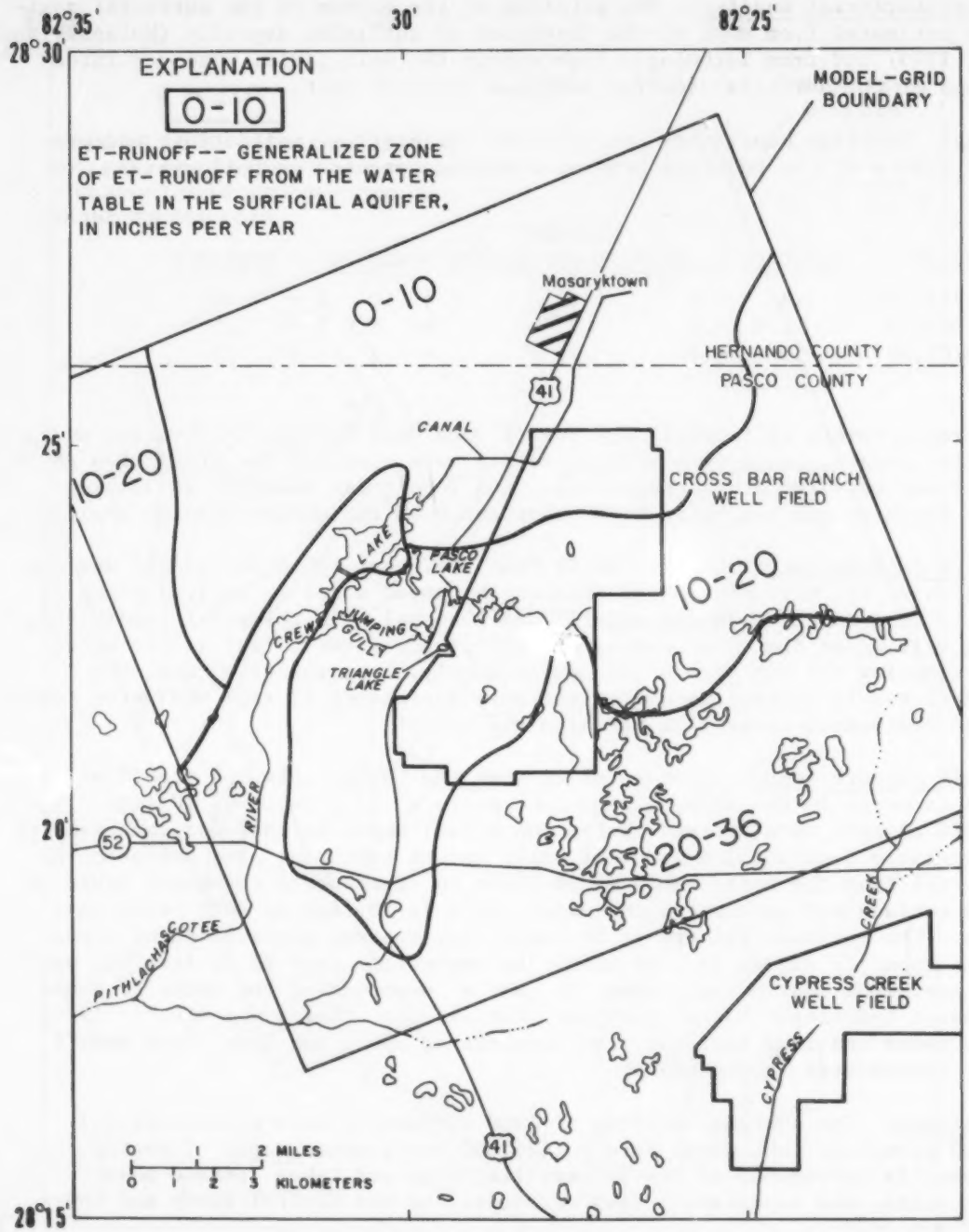

Figure 34.--ET-runoff from the water table in the surficial aquifer for predevelopment conditions.

in accordance with records of operation for each well. Pumping for agricultural and domestic uses was not included in the model because these withdrawals were small. As of 1979, agricultural consumptive-use permits issued by the District totaled about 0.7 Mgal/d within the modeled area. Although several hundred domestic wells lie within 2 miles of the well field (Heath, 1983), their impact on the ground-water flow system is probably small.

Boundary conditions: Initially, a no-flow boundary was input for the surficial aquifer. Flow in the surficial aquifer was considered to be insignificant due to the flat water-table gradient and low hydraulic conductivity. However, a better calibration was obtained by inputting flow rates arbitrarily between 0.1 and 0.6 ft^3/s in 19 grid blocks along the northeast boundary of the model grid where the water-table gradient is steep.

Boundary flow rates in the Upper Floridan aquifer were estimated using the regional well-fields area model (Hutchinson, 1984a). The FORTRAN program was modified to have the regional model compute flow across grid-block faces that coincide with the Cross Bar Ranch model (fig. 30). These flows were apportioned to appropriate grid blocks in the model and then adjusted during calibration. Boundary inflow is small compared to outflow and occurs primarily along the southern edge of the model. Boundary outflow is large along the northern edge of the model grid. The range over individual boundary nodes for the model calibration is from 1 ft^3/s of inflow to 5.6 ft^3/s of outflow.

Calibration

The model was calibrated by systematically adjusting input parameters within acceptable limits until simulated heads in the surficial and Upper Floridan aquifers matched average levels observed between September 1980 and May 1981 (figs. 10 and 11). Because the response of the ground-water system to stress is rapid, lowering recharge and imposing pumping would simply lower water levels to a new steady-state level represented by averaging the maps. Leakance of the upper confining unit, transmissivity of the Upper Floridan aquifer, ET-runoff capture rate, and boundary flow derived from the regional model (Hutchinson, 1984a) were adjusted during calibration of the model.

The model calibration was based on matching simulated heads with observed heads within 5 feet. The $\pm$5 foot error limit is based on probable errors in averaging heads and aquifer properties over a grid block and constructing average water-level maps. For example, a well in a corner of a grid block may have a significantly different observed water level than is computed at the center of the block. Add this error to map error, which is normally one-half the contour interval (in this case 2.5 feet), and $\pm$5 feet seemed to be a reasonable error criterion.

The results of the calibration are assessed by comparing model-simulated and observed water levels in the 529 grid blocks that comprise the model. Model-simulated water levels at nine key grid blocks matched observed levels in wells and at Pasco Lake within the $\pm$5-foot error limit for both the surficial and Upper Floridan aquifers (table 7). Average observed and model-simulated water levels in both aquifers are compared statistically in table 8.

Table 7.--Observed and simulated water levels for model calibration and validation

Well or lake name[1/]		Node in model	Observed water level for September 1980-May 1981 calibration (feet)	Model-simulated water level for calibration (feet)	Estimated water level for September 1976-May 1977 validation (feet)	Model-simulated water level for validation (feet)
Masaryktown	S	5-17	47	50	50	56
	D		32	36	39	42
NRW	S	8-20	47	46	57	54
	D		37	40	48	47
WRW	S	11-13	52	52	59	61
	D		51	48	54	56
NERW	S	11-21	51	52	63	61
	D		45	47	56	54
B-1	S	13-13	60	57	65	65
	D		57	52	60	63
SERW	S	17-15	67	64	71	68
	D		63	61	69	68
SRW	S	20-9	71	68	74	71
	D		69	65	70	69
Gowers Corner	S	23-13	76	73	79	75
	D		71	71	76	74
Pasco Lake		12-11	58	58	61	62

[1/] S denotes shallow well in surficial aquifer; D denotes deep well in Upper Floridan aquifer. See figure 3 for site locations.

Table 8.--Statistics of model calibration

Statistic	September 1980-May 1981 average observed versus model-simulated	
	Water table	Potentiometric surface
Number of active nodes	529	529
Maximum range in residuals[1/] (feet)	6.3 to (-6.1)	5.5 to (-4.5)
Mode of residuals (feet)	-1.2	-3.6
Median residual (feet)	1.4	-0.2
Mean residual (feet)	1.3	-0.2
Mean of absolute values of residuals (feet)	2.2	2.2
Standard deviation of residuals (feet)	2.3	2.6
Correlation coefficient	0.9871	0.9900

[1/] Residuals were computed by subtracting model-simulated water levels from the long-term average potentiometric surface and water table. A negative residual indicates that the model-simulated water level is higher than the long-term average water level, and the reverse is indicated by a positive residual.

Residuals for the 529 grid blocks were nearly within the ±5-foot limit. The standard deviation about the 1.3-foot mean of the residuals for the water table was 2.3 feet. That is, the model-simulated water table matched the average observed level within a range of 1.0 foot above to 3.6 feet below at about 68 percent of the nodes. Similarly, the model-simulated potentiometric surface matched the September 1980 to May 1981 average level at 68 percent of the nodes within a range of 2.8 feet above to 2.4 feet below, based on a standard deviation of 2.6 feet about a residual mean of 0.2 foot above the average level. The correlation coefficients were near one, indicating near-perfect association between the average observed and model-simulated water levels in both aquifers.

The statistics for the calibration are based on the assumption that the residuals between observed and computed water levels are normally distributed about the mean of the residuals. This central tendency is verified when the mean, median, and mode coincide. When the difference between the mean and median is about one-third the difference between the mean and mode, the frequency distribution is moderately skewed, and confidence in the statistical techniques is reduced. Statistics of the model calibration indicate symetrical (no skewness) distributions of residuals for the water table and potentiometric surface, and there is a good match between observed and computed water levels.

Validation

A model gains additional validation as a predictive tool when it is successfully tested against a data set that represents hydrologic conditions different from those used for calibration. Average estimated water levels for September 1976 to May 1977 (figs. 8 and 9) were used to validate the Cross Bar Ranch model. All pumpage was removed from the calibrated steady-state model, boundary flows were adjusted using the regional well-fields model, and the September 1976 to May 1977 heads were input. Finally, the recharge rate was increased from 20 in/yr to 25 in/yr, based on the assumption that rainfall, and therefore recharge, was 5 inches above that of the September 1980 to May 1981 calibration period. The long-term average recharge rate is assumed to be 28 in/yr. Thus, the model would simulate water levels under predevelopment conditions with slightly lower than normal recharge.

The validation results were assessed by comparing model-simulated and estimated water levels in the 529 grid blocks that comprise the model. Model-simulated water levels at nine key grid blocks matched estimated levels and at Pasco Lake within ±6 feet for both the surficial and Upper Floridan aquifers (table 7). Statistics of comparisons at all 529 grid blocks are listed in table 9. Comparisons are good statistically; thus, the model was considered to be adequately validated.

Table 9.--Statistics of model validation

Statistic	September 1976-May 1977 average observed versus model-simulated	
	Water table	Potentiometric surface
Number of active nodes	529	529
Maximum range in residuals[1/] (feet)	4.9 to (-7.7)	6.0 to (-5.0)
Mode of residuals (feet)	0.8	0.6
Median residual (feet)	0.4	0.4
Mean residual (feet)	-0.1	0.2
Standard deviation of residuals (feet)	2.8	1.9
Mean of absolute values of residuals (feet)	2.3	1.6
Correlation coefficient	0.9784	0.9922

[1/] Residuals were computed by subtracting model-simulated water levels from the calibrated steady-state water table and estimated prestressed potentiometric surface, respectively. A negative residual indicates that the model-simulated water level is higher than the water level with which it is compared, and the reverse is indicated by a positive residual.

The model results indicate that, on the average, the simulated water table was 0.1 foot above the average estimated level. The maximum deviation was 7.7 feet above the estimated water table. The standard deviation of 2.8 feet about the mean indicates that, at about 68 percent of the grid blocks, the model-simulated water table remained within a range of 2.7 feet below and 2.9 feet above the estimated level. A correlation coefficient of 0.9784 indicates a good correlation between the two surfaces.

Comparison of model-simulated and September 1976-May 1977 potentiometric surfaces was good statistically. Over the 529 nodes within the model-grid boundary, the simulated potentiometric surface ranged from 5.0 feet above to 6.0 feet below the estimated level. The mean was 0.2 foot below the estimated level. The standard deviation about the mean of the residuals was 1.9 feet, which indicates the model-simulated potentiometric surface matched within a range of 1.7 feet above to 2.1 feet below the estimated level at about 68 percent of the nodes. A correlation coefficient of 0.9922 indicates a good correlation between the two surfaces. Analyses for normality indicate moderate skewness in the distributions of residuals for the water table and potentiometric surface. Although confidence in the statistics of the model validation is reduced, they strongly indicate that there is a good match between estimated and computed water levels.

Sensitivity Analysis

Sensitivity analysis tests model response to changes in input parameters. Separate model simulations are made with individual parameters varied in turn over a reasonable range of values within which they could occur. The model was not recalibrated each time parameter values were changed because this would be impractical in terms of time and cost. Exact values of head changes from sensitivity analyses should be viewed critically, but relative changes can provide insight as to the degree to which a change in any parameter may affect results of model simulation.

Model sensitivity was tested by varying ET-runoff rate and depth, recharge, hydraulic conductivity of the surficial aquifer, transmissivity of the Upper Floridan aquifer and hydrologic anomaly, leakance of the upper confining unit, and boundary flows. Table 10 summarizes ranges in water-level change in response to uniform changes in parameter values. Figure 35 shows deviations from the predevelopment water table and potentiometric surface due to changing maximum ET-runoff capture depth (ETD) by $\pm$5 feet, recharge rate (R) by $\pm$20 percent, and potential ET-runoff capture rate (ETR) by $\pm$20 percent. Figure 36 shows deviations due to changing boundary flow (FLO) in the Upper Floridan aquifer by $\pm$20 percent, transmissivity (T) of the Upper Floridan aquifer by factors of 2 and 0.5, leakance (TK) of the upper confining unit by factors of 2 and 0.5, and increasing transmissivity of the hydrologic anomaly from 6,600 to 1,000,000 ft^2/d. The cross sections in both figures depict model-simulated heads along column 13 of the model. This column passes through the center of the model and intersects the hydrologic anomaly. The two cross sections were used in conjunction with drawdown maps output by the model to supply areal perspective to the sensitivity analysis.

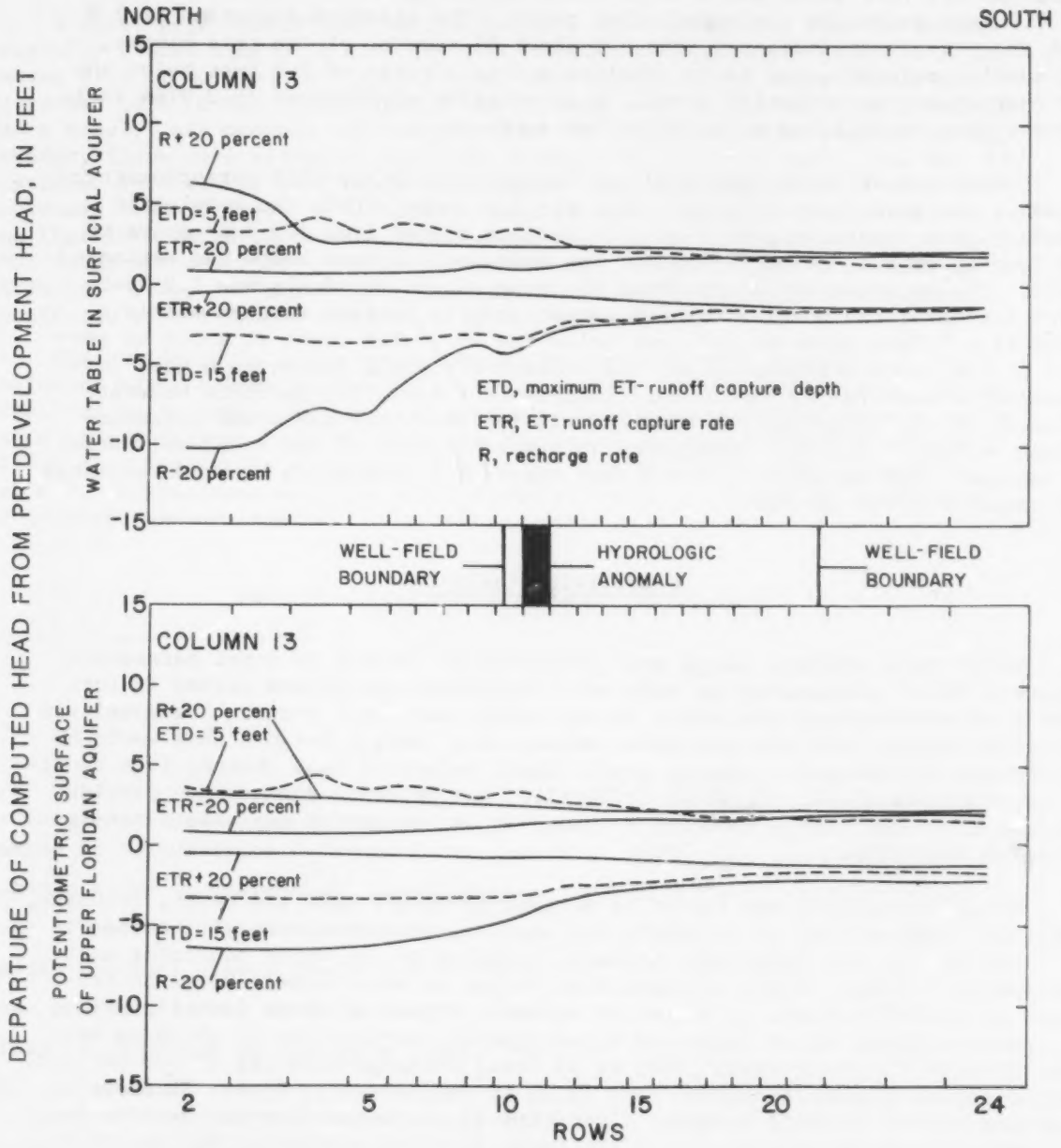

Figure 35.--Effects of varying ET-runoff and recharge parameters.

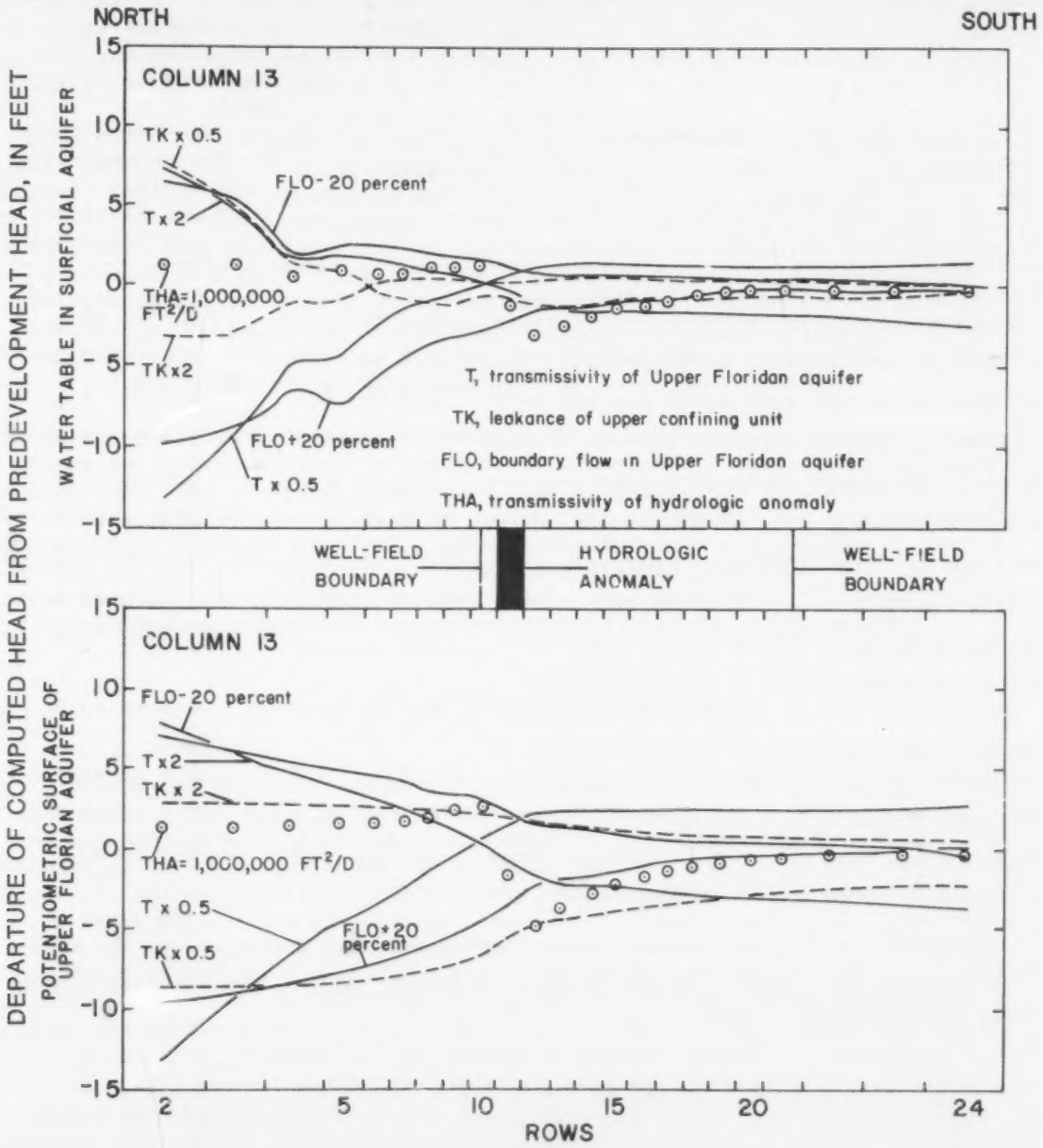

Figure 36.--Effects of varying boundary flow and hydraulic parameters.

Table 10.--Range in head fluctuations resulting from model-sensitivity tests

Parameter and change	Range[1] of head fluctuation below (-) and above (+) starting head (feet)	
	Water table in surficial aquifer	Potentiometric surface of Upper Floridan aquifer
Hydraulic conductivity of surficial aquifer x 3	-1.8 to +0.9	-0.9 to +0.1
Increase ET-runoff rate by 20 percent	-2.3 to 0.0	-1.6 to 0.0
Decrease ET-runoff rate by 20 percent	0.0 to 5.0	0.0 to 3.6
Increase ET-runoff depth to 15 feet	-4.2 to 0.0	-3.4 to 0.0
Decrease ET-runoff depth to 5 feet	0.0 to +4.3	0.0 to +3.3
Increase recharge rate by 20 percent	0.0 to +6.5	0.0 to +3.7
Decrease recharge rate by 20 percent	-12.3 to 0.0	-6.6 to 0.0
Change leakance x 2	-10.5 to +1.3	0.0 to +3.5
Change leakance x 0.5	-2.9 to +8.2	-10.5 to 0.0
Change transmissivity of Upper Floridan aquifer x 2	-2.7 to 7.6	-4.6 to +9.7
Change transmissivity of Upper Floridan aquifer x 0.5	-13.6 to 3.4	-13.4 to +4.4
Increase boundary flow by 20 percent	-9.9 to +0.3	-9.9 to +0.4
Decrease boundary flow by 20 percent	-0.3 to +6.9	-0.5 to +7.0
Transmissivity of hydrologic anomaly = 10^6 ft^2/d	-3.0 to +3.1	-5.0 to +4.2

[1] Represents range of model-computed residuals between starting and ending heads for 529 grid blocks.

There is a marked contrast in the model's sensitivity north and south of the hydrologic anomaly. This contrast appears to be linked more to ET-runoff capture than to the presence of the anomaly. ET-runoff is the variable source from which water is derived in the model. South of the anomaly, where the water table is within 10 feet of land surface, head changes are dampened by the capture of ET-runoff. For example, if 3.8 inches of water are captured in a grid block by lowering the water table 1 foot, large quantities of water would have to be removed to significantly lower heads. North of the hydrologic anomaly, the water table generally is below the ET-runoff capture zone. Changes in flux

north of the anomaly (caused by changing model parameters) are absorbed by ET-runoff capture south of the anomaly because other fluxes (recharge and boundary) are constant in the model. Water levels in the north must change to such a degree as to induce changes in ET-runoff capture in the south. Thus, head changes are less in the south compared to changes in the north because of the south's proximity to the source of water.

The hydrologic anomaly has an important role in the model's sensitivity. It acts as the hinge line between areas of high and low response to parameter changes. Because the anomaly is modeled as a zone of low transmissivity in the Upper Floridan aquifer, it acts as a dam that retards flow northward through the aquifer. Head changes north of the anomaly must be large to induce compensating changes in flow through the low transmissivity zone. Increasing the transmissivity of the anomaly to a very high value (1,000,000 ft^2/d) results in drawdown in the south and buildup in the north because water easily flows through this zone. Observed conditions are better simulated when the anomaly acts as a low-transmissivity zone that dams up water in the south.

Of the parameters tested, the model is very sensitive to probable ranges of change in transmissivity and boundary flow within the Upper Floridan aquifer and leakance. Varying these parameters generally resulted in a range in head fluctuations greater than 10 feet in one or both aquifers. For the principal aquifer (Upper Floridan aquifer), the model is moderately sensitive to changes in ET-runoff and recharge parameters as these changes produce a range of head fluctuations generally between 2 and 10 feet. The model is relatively insensitive to changes in the hydraulic conductivity of the surficial aquifer.

Limitations of Model Application

A conceptual approach to ground-water modeling was used in the application of this model. The hydrogeologic system was conceptualized, its parameters identified and estimated, and it was transformed to the mathematical analog. The mathematical model approximates the physical processes that control the conceptual model, but it is only an approximate representation of the prototype.

The hydrogeology has been simplified to the extent that an operational mathematical model could be constructed. The mathematical solution is an approximate solution to the differential equations that define the system. Although the model is local in nature, it is not practical to track the movement of every drop of water in the system. Therefore, the very localized impact of pumping small quantities of water will not be accurately simulated. The impact of pumping large quantities of water near the model-grid boundary may not be accurately depicted because changes in boundary flow through large grid blocks in the regional model may not be accurately apportioned to small grid blocks in the Cross Bar Ranch model. A model limitation that could lead to significant errors occurs when the water table rises above land surface or falls to the base of the surficial aquifer. Theoretically, the water table cannot rise above land surface because runoff would occur. When the water table falls below the base of the surficial aquifer in a grid block, as was the case under the 45-Mgal/d pumping rate, that block becomes inactive, resulting in cessation of leakage to the Upper Floridan aquifer. When boundary grid

blocks go dry, the cone of depression expands to dewater adjacent grid blocks and eventually causes a chain reaction. The model will flag grid blocks where the computed water table is above land surface or below the bottom of the aquifer. The model also only grossly accounts for changes in recharge, ET, and runoff that result from changes in the water table. Because the model assumes a steady-state condition, the solution is not time dependent, and the time required for computed heads to reach these levels cannot be determined from this model.

The Cross Bar Ranch predictive-model runs exemplify the types of analyses possible with the ground-water flow model. Generally, the model can be used to compute water-balance and water-level changes in response to various distributions of pumping and conditions of recharge. Because the model simulates long-term average water-level changes, short-term high or low conditions could be significantly different from simulated conditions. Ideally, the model should represent all characteristics of the prototype, but realistically, it represents a few of the more important characteristics of the hydrologic system. The model reasonably simulates the ground-water system in the Cross Bar Ranch well-field area. Additional limitations that pertain to modeling applications in Florida are discussed by Hutchinson (1984b).

Listing of Model-Input Data

A sample input-data listing is provided for the predictive run where the well field is pumped at 30 Mgal/d. The listing contains 662 lines or computer cards, including one card for each of the 17 pumping wells. Each card is keyed to data-deck instructions (Hutchinson, 1984a) by group number, card number, and variable name. The listing is convenient for looking up a particular input parameter for any grid block in the model.

There are four groups of cards in the data deck:

Group I. This group contains data that dimensions the model into a 25 x 25 array and provides several job-control options.

Group II. This group contains scalar parameters for mapping computed drawdowns, head, head difference, recharge, ET-runoff, leakage, pumping, and boundary flow. It also provides tolerances for computational errors.

Group III. This group contains the data matricies, 17 of which comprise the input parameters to this model. To reduce programming time and the number of layers, a "leakance" array replaces transmissivity, storage, and head arrays that would be necessary to represent the confining bed.

Group IV. This group controls the distribution of pumping and boundary flow over the model area. The model computes the response of the hydrologic system that will result from imposing pumping upon the system.

Usually, Groups I, II, and III remain unchanged from the calibrated model. To determine the effects of pumping stresses on the system, Group IV is the only group in which cards are changed.

SAMPLE INPUT DATA DECK FOR CROSS BAR RANCH WELL FIELD PUMPAGE PROBLEM

DATA SET	GROUP	CARD	VARIABLE
CROSS BAR RANCH MODEL PREDICTIVE RUN	I	1	HEADING
PUMP AT 30 MGAL/D		2	HEADING
		3	
25 25 2 30 0		4	
DRAW HEAD MASS WATE RECH PUMP ITER			
	II	1	
1 1 .01 2 1.0		2	
5280 5280 1 112 112 11 12 12 11 -11 MILES		3	
		4	
		5	
	III	1	STRT1

1 1 0

0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
0.0
0.0 25.0019 26.0369 27.5603 28.5982 29.3013 29.5460 30.2312
30.7027 31.0650 31.4307 31.7826 32.1443 32.5581 32.9844 33.4651
33.9819 34.5761 35.2085 35.9281 36.7964 37.9428 38.9345 40.3893
0.0
0.0 27.5421 29.9819 31.8083 32.9920 33.6862 34.1348 34.6191
34.9421 35.2574 35.5870 35.9369 36.2731 36.6103 36.9710 37.3511
37.7925 38.2659 38.7233 39.1904 39.7625 40.5331 41.1899 41.6796
0.0
0.0 29.9313 32.8987 34.3648 36.1381 36.8473 37.3415 37.7641
38.1108 38.4563 38.8026 39.1191 39.3747 39.6880 40.0101 40.3495
40.7109 41.0621 41.3993 41.7465 42.1744 42.7303 43.1477 43.2353
0.0
0.0 31.9194 35.1838 37.2835 38.6001 39.3063 39.7901 40.2222
40.6110 40.9722 41.2834 41.5124 41.7453 42.0022 42.2571 42.5460
42.8383 43.1115 43.3866 43.6902 44.0783 44.5295 44.7311 44.3568
0.0
0.0 33.1383 36.6912 38.9356 40.2556 40.9478 41.4234 41.8577
42.2527 42.6036 42.9965 42.9798 43.1593 43.3367 43.5957 43.9782
44.2146 44.3821 44.6100 44.9318 45.3836 45.7954 45.9816 45.5019
0.0
0.0 34.1629 37.8382 40.1551 41.4507 42.1060 42.5473 42.9840
43.3946 43.7678 44.1362 44.4628 44.7386 44.9544 45.1495 45.2689
45.3532 45.4169 45.6573 46.0591 46.5429 46.8939 46.8881 46.4127
0.0
0.0 35.4912 39.0169 41.9814 43.2129 43.7466 44.1160 44.5492
45.0160 45.5187 46.0452 46.5687 46.9117 47.1495 47.2603 47.1287
47.0156 46.7547 47.0169 47.7889 47.9847 48.1298 47.9661 47.4836
0.0
0.0 37.3613 41.5102 44.1750 45.3795 45.6906 46.0750 46.5570
47.1060 47.7479 48.2994 48.7314 49.0844 49.3710 49.5079 49.4119
49.1701 51.1755 51.4792 50.4234 50.0654 49.6837 49.1144 48.5864
0.0
0.0 39.3559 43.8746 46.1924 47.4365 47.4167 47.3915 48.4447
48.9588 49.6403 50.2205 50.6758 51.0369 51.3270 51.5618 51.7584
54.3663 56.2499 55.7771 53.5569 52.7743 51.4177 50.7671 50.0976
0.0
0.0 41.9767 46.4947 48.9141 50.6026 52.0415 53.3423 54.1939
54.5137 55.6430 56.4231 56.9299 57.2788 57.5199 57.6950 57.9641
59.2478 58.8232 58.1707 56.9594 55.4084 53.9600 52.9424 52.0155
0.0
0.0 44.7368 46.0035 51.7503 54.0916 56.5072 57.9435 59.0417
59.9461 60.7715 61.4214 61.9419 62.2936 62.4809 62.5174 62.2172
61.6251 61.1602 60.6095 59.7929 58.4216 56.7482 55.6112 54.3272
0.0
0.0 46.9709 50.9014 53.8358 56.2239 58.0307 59.3416 60.3551
61.2881 62.0858 62.7169 63.2129 63.5594 63.7683 63.8430 63.7638
63.5152 63.2333 62.8339 62.2319 61.2931 59.7349 58.4533 56.8706
0.0
0.0 49.1416 52.7344 55.7287 58.0941 59.6778 60.8435 61.8351
62.6763 63.3969 63.9911 64.4608 64.8001 65.0247 65.1516 65.2121
65.1686 65.0402 64.7523 64.2835 63.6282 62.2569 60.9230 59.1186
0.0
0.0 51.2195 54.4984 57.3553 59.8191 61.2506 62.3111 63.2436
64.0317 64.6975 65.2431 65.6762 66.0025 66.2337 66.3996 66.3539
66.6290 66.6165 66.4444 66.1016 65.6264 64.4117 63.09C6 61.2205
0.0
0.0 53.1797 56.2181 59.2914 61.4613 62.7673 63.735C 64.5955
65.3319 65.9604 66.466C 66.8453 67.1549 67.3733 67.5655 67.8047
67.9638 67.9935 67.8922 67.6374 67.290C 66.2437 65.0041 63.1830
0.0
0.0 54.9120 57.9305 60.9200 62.9844 64.2C46 65.1084 65.9C69
66.5710 67.1416 67.6258 67.9884 68.264C 68.4697 68.675C 68.9540
69.1466 69.2093 69.1535 68.9586 68.7116 67.8237 66.7212 65.0906

```
 0.0
 0.0      56.4040   59.5469   62.4329   64.4046   65.5405   66.4049   67.1406
67.7678   68.3159   68.7483   69.0728   69.3122   69.5298   69.7435   70.0255
70.2290   70.3129   70.285C   70.1512   69.9632   69.2C20   68.2572   66.8830
 0.0
 0.0      57.7118   6C.9417   63.7822   65.6584   66.7465   67.54C9   68.2126
68.7989   69.3460   69.7574   70.0421   7C.2773   70.5C26   7C.7184   70.9655
71.1600   71.2612   71.255C   71.1699   71.004C   70.3676   69.5932   68.5468
 0.0
 0.0      58.9115   62.1744   64.9616   66.7715   67.8C77   68.5441   69.1941
69.7648   70.2568   7C.6497   70.9423   71.1775   71.3877   71.57C6   71.7800
71.9584   72.0883   72.0785   72.0C60   71.8501   71.3453   7C.74C6   70.0C72
 C.0
 0.0      60.1377   63.5788   66.2772   68.0394   69.C196   69.705e   70.3475
70.9206   71.3787   71.7307   71.9970   72.2022   72.3677   72.5049   72.6573
72.7795   72.8438   72.8366   72.7625   72.6608   72.3631   71.9541   71.5331
 0.0
 0.0      61.6206   65.2921   67.9992   69.8207   70.8C20   71.4839   72.C755
72.5780   72.9880   73.2547   73.4386   73.5583   73.6380   73.6957   73.7547
73.7889   73.7908   73.7684   73.7182   73.6744   73.5367   73.3335   73.0922
 0.0
 0.0      63.4934   67.1023   69.8402   71.6575   72.6955   73.43C2   74.0540
74.5543   74.9374   75.1337   75.1717   75.0905   74.9897   74.9114   74.8430
74.7504   74.6397   74.5915   74.5564   74.5271   74.4586   74.4392   74.3217
 0.0
 0.0      66.1656   68.9967   71.5569   73.6179   74.9515   75.9864   76.8481
77.3812   77.6748   77.6349   77.2965   76.7332   76.1646   75.7154   75.3889
75.1919   75.1216   75.0654   75.0203   74.9745   74.8463   75.203e   74.9288
 0.0
 0.0       0.C       C.0       0.0       C.0       0.C       0.0       0.C
 0.0       0.C       C.0       0.0       C.0       0.C       C.0       0.C
 0.0       0.0       C.0       0.0       C.0       0.C       0.0       0.C
 0.0
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   1         1         C                                                                    III         1         STRT2
 0.0       0.C       C.0       0.0       0.0       0.C       C.0       0.C
 0.0       0.C       C.0       0.0       C.0       0.C       C.0       0.C
 0.0       0.C       C.0       0.0       C.0       0.C       C.0       C.C
 0.0
 0.0      29.1864   33.5015   40.4997   41.0161   43.2728   44.0477   45.1306
50.1722   50.6357   52.3419   52.9572   53.3638   53.7710   54.2082   54.6800
55.1281   55.2686   56.3280   57.1609   58.4712   59.C774   66.9548   84.4168
 0.0
 0.0      31.3765   36.154C   43.8958   46.8838   47.7114   48.2261   48.6969
49.1898   50.C973   55.5014   56.6169   57.1398   57.5126   57.8467   58.C594
58.1786   58.2972   58.4252   58.5537   58.7315   59.C201   65.3596   81.1143
 0.0
 0.0      34.7873   39.1427   45.0774   49.9564   50.8486   51.3253   51.7407
52.1032   52.5425   53.0587   53.7C11   56.2275   56.4C42   56.5575   56.6757
56.7714   56.8623   56.9558   57.1151   58.5674   58.7959   61.2393   70.7107
 0.0
 0.0      36.8252   44.3258   50.6271   52.2094   52.6596   51.3499   51.4749
51.6972   54.2191   54.7919   55.0C86   54.8444   50.5515   55.1981   56.9303
57.1140   57.2136   57.4101   57.5818   59.094C   59.3696   61.5749   70.1675
 0.0
 0.0      38.2C24   44.5167   47.6382   48.9529   49.6450   49.8125   50.1471
50.3312   50.4220   5C.7775   50.8568   5C.9269   50.8704   51.19C4   52.6C25
52.9446   53.5157   57.3045   57.7792   60.7746   63.C127   61.8523   64.3680
 0.0
 0.0      41.C986   45.1178   48.5492   48.9279   50.C399   47.9469   49.3664
49.4634   46.4059   5C.9756   51.3436   51.480C   51.5787   51.672C   51.7841
51.9016   53.3886   54.4314   55.4416   61.0846   63.4767   62.2345   64.3C94
 0.0
 0.0      41.5883   47.0343   49.4227   49.4080   49.3322   46.0621   46.1853
46.5383   47.8143   51.6975   52.C372   52.2131   52.4105   52.3202   52.2648
52.2743   53.5635   54.4355   55.7936   61.8594   63.9558   64.5524   64.8457
 0.0
 0.0      43.4060   48.1196   49.6834   51.0391   46.8740   46.9465   47.3250
49.3063   54.2913   55.1586   53.2838   53.460C   55.7155   55.743e   55.7188
55.7578   57.5683   58.38C5   57.6766   58.3076   66.2C24   66.96CC   68.9971
 0.0
 0.0      44.2886   48.9557   47.4153   48.4821   47.9190   52.3285   54.5342
51.2139   55.7406   56.3252   56.4851   56.6727   56.9722   58.5814   58.9548
60.5799   61.5332   62.1807   60.9163   60.5548   66.8374   67.52C2   69.6568
 0.0
 0.0      45.6846   5C.2769   48.3496   49.3963   54.369C   57.4652   58.0430
57.0523   59.CC06   61.4897   61.8887   62.0752   62.2C73   62.3723   62.5258
63.1155   62.9676   62.7514   63.0253   62.6965   67.4864   68.0439   70.1649
 0.0
 0.0      48.8499   52.0248   52.9430   55.466C   58.1774   59.9392   60.5328
61.0251   63.6073   63.3857   64.8708   65.104C   65.2C76   65.2259   65.0950
64.8393   64.2811   64.8953   65.8124   65.4771   68.2414   68.09C8   70.7481
```

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 0.0
 0.0      50.0826   53.0508   56.7774   58.1692   59.2804   61.2361   61.4442
61.9835   64.5068   64.9449   65.6809   65.8827   65.9902   66.0283   65.9909
65.9266   66.6575   67.3724   67.3570   66.9258   69.0546   68.8131   71.3879
 0.0
 0.0      51.2326   53.9587   57.1096   60.1075   61.8845   63.8316   64.4178
64.8603   65.3510   66.0882   66.7892   66.9862   67.0999   67.1660   67.2187
67.6482   68.5203   68.6415   69.4352   68.1675   70.4332   70.1258   71.9644
 0.0
 0.0      53.2098   54.4316   59.8050   61.5869   63.2500   64.7521   66.1063
66.5680   66.9517   67.2707   67.8667   68.0812   68.1633   68.2510   68.3930
68.5340   69.8174   70.4107   71.8005   70.5248   72.3205   71.3733   72.4280
 0.0
 0.0      53.1276   54.9991   62.1431   64.2248   64.9925   65.9838   66.5425
67.7484   68.8828   69.1781   69.2186   69.0834   68.3699   68.4926   69.9172
70.4746   70.5994   71.1373   71.8698   71.3859   72.8974   71.9567   72.3058
 0.0
 0.0      56.0478   58.1646   66.0104   65.6345   66.6808   67.7061   68.9392
68.5125   68.4816   69.9018   70.0764   70.1363   68.9974   69.1315   70.9648
71.1997   71.2640   71.7209   71.2967   72.0925   73.4151   73.1237   73.3904
 0.0
 0.0      56.4135   62.1629   66.2309   68.1360   68.0271   70.5341   71.0009
71.2728   72.0310   71.9173   71.9374   70.8144   70.8327   71.0367   72.4764
72.6440   72.6936   72.6662   71.8470   73.6021   75.0534   74.8349   73.9589
 0.0
 0.0      57.4997   63.0503   67.8632   68.9043   69.9015   71.1917   70.7313
70.3000   72.9912   73.2396   71.7398   71.3486   71.8917   72.8366   73.0608
73.1724   73.2939   72.2615   73.2189   74.1796   75.4501   75.2873   75.6576
 0.0
 0.0      58.1703   63.7564   68.5077   69.4772   70.4447   70.8442   71.1739
71.4830   71.8686   72.4785   72.5705   72.6828   73.2178   73.3721   73.4876
73.6504   75.3170   74.5685   74.5291   74.6554   75.7127   75.5892   76.0822
 0.0
 0.0      59.7429   66.2822   69.1973   70.1343   70.6045   70.1556   71.3461
72.9535   73.2689   73.4487   73.5819   73.6862   73.7818   73.8566   73.9312
73.9963   74.0709   74.0819   74.6569   75.9645   75.9937   75.8927   75.8129
 0.0
 0.0      61.9485   67.2241   70.1048   72.4437   72.9672   73.3050   73.6190
73.9334   74.9815   74.2942   74.3454   74.3957   74.4357   74.4696   74.4991
74.5157   74.5128   74.5356   74.9290   76.2814   76.3075   76.2571   76.2080
 0.0
 0.0      62.9299   68.6303   72.4527   73.4218   73.9504   74.3239   74.6447
74.9678   76.4855   76.6434   76.6215   75.7188   75.6385   76.0256   76.0102
75.9364   75.2662   76.4438   76.5688   77.2395   77.2429   77.2484   77.9426
 0.0
 0.0      64.7507   69.5930   72.8628   74.4030   75.0874   75.6075   76.0431
76.3871   77.8602   77.9167   77.7957   78.3477   77.2038   76.4985   76.3327
76.6829   76.6873   76.6862   76.6761   76.6510   75.9214   76.0137   77.3899
 0.0
 0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
 0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
 0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
 0.0
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      0.0          0          0                                                                                  111      1        S1
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      0.0          0          0                                                                                  111      1        S2
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     .0058         1          0        1.0       1.0
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   175 175 225 225 225 225 225 290 290 290 350 350 350 350 400 400 400 400 400
400 400 400 400
   175 175 225 225 225 225 225 290 290 290 290 350 350 350 350 350 400 400 400
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   175 175 225 225 225 225 225 225 225 225 290 290 290 290 290 290 350 350 350
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   175 175 175 175 175 175 175 175 175 175 225 225 290 29  290 290 350 350 350
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225 225 225 225
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100 225 225 225
    80  80  80  80  80  80  80  80  80  80  80  80  80  80  80  80  12  50  50  50
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100 100 100 100
     50  50  50  50  50  12  12  12  12  12  12  12  12  12  12  12  50  50  50  50
 82  82  82  82  82
     80  80  80  80  80  80  80  80  80  80  80  80  80  80  80  80  50  50  50  50  50
 50  50  50  50  50
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         1          1          C                                                                              III          1          BOTTOM


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33.033.039.065.0
     1.0 7.018.027.028.030.03C.03C.03C.035.035.035.035.035.033.033.033.033.033.0
33.033.038.055.0
     5.010.018.025.03C.033.033.033.033.03C.03C.03C.03C.03C.03C.03C.03C.03C.03C.0
32.032.035.045.0
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45.044.044.046.0

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      0.0          0          C                                                                              III          1          QRE1
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2.64E-09           0          C                                                                              III          1          QRE2


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```

0.0	0	C	III	1	CSS1
1.02E-08	0	C	III	1	CSS2
0.0	0	0	III	1	HSS1
1	1	C	III	1	HSS2

```
   24.030.04C.040.045.045.05C.05C.05C.055.055.06C.065.062.062.060.055.C58.058.0
58.058.064.09C.0
   26.032.043.052.053.055.055.06C.060.065.065.060.06C.06C.058.058.058.058.058.0
58.058.063.080.0
   3C.035.043.050.055.060.06C.065.062.055.055.055.055.055.055.055.055.055.055.0
57.057.060.07C.0
   32.042.055.055.055.050.05C.05C.055.055.055.055.055.055.055.055.055.055.055.0
57.057.060.07C.0
   35.044.055.052.052.050.05C.05C.05C.05C.05C.05C.05C.05C.055.055.055.055.055.C
59.062.060.06C.0
   40.044.050.048.05C.045.048.048.04C.05C.05C.05C.05C.05C.05C.05C.050.053.055.054.0
59.062.060.060.0
   40.049.050.048.048.040.04C.04C.042.05C.050.05C.05C.05C.05C.05C.050.053.055.06C.0
60.062.063.06C.0
   42.047.048.050.04C.040.04C.044.055.055.050.05C.055.055.055.055.057.C6C.062.0
65.065.066.066.0
   42.047.041.042.04C.050.055.045.055.055.055.055.055.06C.06C.06C.06C.062.062.0
65.065.066.066.0
   42.047.04C.040.05C.055.055.052.055.06C.06C.060.06C.060.06C.06C.06C.06C.062.0
65.065.066.066.0
   46.048.047.05C.053.055.055.055.06C.058.061.061.061.061.061.061.06C.062.065.0
65.065.065.066.0
   46.048.053.053.053.056.055.055.06C.06C.061.061.061.061.061.061.061.065.065.0
65.065.065.066.0
   46.048.051.055.057.06C.06C.06C.06C.061.062.062.062.062.062.063.065.065.065.0
65.066.066.066.0
   48.047.055.056.058.06C.062.062.062.062.063.063.063.063.063.063.066.067.068.0
68.068.067.067.0
   5C.046.058.060.06C.061.062.063.065.065.062.064.062.062.065.066.066.067.067.0
68.068.067.067.0
   5C.051.06C.061.062.063.065.063.062.065.065.065.062.062.066.066.066.067.065.0
68.068.068.068.0
   49.058.063.065.063.068.068.068.069.068.068.065.065.065.068.068.068.068.066.0
70.070.070.069.0
   50.058.065.065.066.068.066.064.070.07C.066.065.066.068.068.068.068.068.068.0
70.07C.070.071.0
   50.058.C65.065.066.066.066.066.066.067.067.067.068.068.068.068.072.07C.07C.0
70.070.070.071.0
   52.062.065.065.065.063.065.068.068.068.068.068.068.068.068.068.068.068.068.0
70.070.070.07C.0
   55.062.065.068.068.068.068.068.07C.068.068.068.068.068.068.068.068.C68.068.0
70.07C.070.07C.0
   55.063.068.068.068.068.068.068.071.071.071.069.069.07C.070.070.068.07C.07C.0
71.071.071.072.0
   56.063.067.068.068.068.068.068.071.071.071.073.071.07C.07C.07C.07C.07C.07C.0
70.069.069.071.0
```

```
      0       0       C                                                                                  III     1       HB1
      1       1       C                                                                                  III     1       HB2
     34  40  50  50  55  55  60  60  60  65  65  70  75  72  72  70  65  68  68
68   68  74 100
     36  42  53  62  63  65  65  70  70  75  75  70  70  70  68  68  68  68  68
68   68  73  90
     40  45  53  60  65  70  70  72  70  65  65  65  65  65  65  65  65  65  65
67   67  70  80
     42  52  65  65  65  60  60  60  65  65  65  65  65  65  65  65  65  65  65
67   67  70  80
     45  54  65  62  62  60  60  60  60  60  60  60  60  60  65  65  65  65  65
69   72  70  70
     50  54  60  58  60  55  58  58  50  60  60  60  60  60  60  60  63  65  64
69   72  70  70
     50  59  60  58  58  50  50  50  52  60  60  60  60  60  60  60  63  65  70
70   72  73  70
     52  57  58  60  50  50  50  54  65  65  60  60  65  65  65  65  67  70  72
75   75  76  76
     52  57  51  52  50  60  65  55  65  65  65  65  65  70  70  70  70  72  72
75   75  76  76
     52  57  50  50  60  65  65  62  65  70  70  70  70  70  70  70  70  70  72
75   75  76  76
     56  58  57  60  63  65  65  65  70  68  71  71  71  71  71  71  70  72  75
75   75  75  76
     56  58  63  63  63  66  65  65  70  70  71  71  71  71  71  71  73  75  75
75   75  75  76
     56  58  61  65  67  70  70  70  70  71  72  72  72  72  72  73  75  75  75
75   76  76  76
     58  57  65  66  68  70  72  72  72  72  73  73  73  73  73  73  76  77  78
78   78  77  77
     60  56  68  70  70  71  72  73  75  75  72  74  72  72  75  76  76  77  77
78   78  77  77
     60  61  70  71  72  73  75  73  72  75  75  75  72  72  76  76  76  77  75
78   78  78  78
     59  68  73  76  73  79  79  79  80  79  79  76  76  76  79  79  79  79  77
81   81  81  80
     60  68  76  76  77  79  77  75  81  81  77  76  77  79  79  79  79  79  79
81   81  81  82
     60  68  76  76  77  77  77  77  77  78  78  78  79  79  79  79  82  81  81
81   81  81  82
     62  72  76  76  76  73  76  79  79  79  79  79  79  79  79  79  79  79  79
81   81  81  81
     65  72  76  79  79  79  79  79  81  79  79  79  79  79  79  79  79  79  79
81   81  81  81
     65  73  79  79  79  79  79  79  82  82  82  80  80  81  81  81  79  81  81
82   82  82  82
     66  73  78  79  79  79  79  79  82  82  82  83  82  81  81  81  81  81  81
81   80  80  82
```

```
      1       1       C                                                                                  III     1       DELX
   5280    5280    3960    3960    2640    1760    1760    1760
   1760    1760    1760    1760    1760    1760    1760    1760
   1760    1760    1760    1760    2640    3960    3960    5280
   5280
```

```
      1       1       C                                                                                  III     1       DELY
   5280    5280    3960    3960    2640    1760    1760    1760
   1760    1760    1760    1760    1760    1760    1760    1760
   1760    1760    1760    1760    2640    3960    3960    5280
   5280
```

```
      1                                                                                                  III     1       DELZ
      1       0     124       1       1       1      24
      1      19      13   -2.73    CB-1
      1      18      13   -2.73    CB-2
      1      17      11   -2.73    CB-3
      1      17      13   -2.73    CB-4
      1      15      14   -2.73    CB-5
      1      14      12   -2.73    CB-6
      1      14      13   -2.73    CB-7
      1      13      14   -2.73    CB-8
      1      12      14   -2.73    CB-9
      1      11      16   -2.73    CB-10
      1      11      18   -2.73    CB-11
      1      12      19   -2.73    CB-12
```

1	10	18	-2.73	CB-13
1	11	20	-2.73	CB-14
1	9	16	-2.73	CB-15
1	8	18	-2.73	CB-16A
1	9	20	-2.73	CB-17
1	2	2	-4.19	
1	2	3	-5.01	
1	2	4	-5.73	
1	2	5	-3.93	
1	2	6	-2.57	
1	2	7	-2.37	
1	2	8	-2.37	
1	2	9	-3.16	
1	2	10	-2.96	
1	2	11	-3.06	
1	2	12	-3.44	
1	2	13	-3.74	
1	2	14	-3.44	
1	2	15	-3.73	
1	2	16	-3.83	
1	2	17	-3.83	
1	2	18	-3.66	
1	2	19	-3.86	
1	2	20	-2.86	
1	2	21	-3.72	
1	2	22	-4.82	
1	2	23	-4.58	
1	2	24	-2.77	
1	3	2	-2.53	
1	3	24	-0.43	
1	4	2	-2.95	
1	4	24	-1.02	
1	5	2	-1.95	
1	5	24	-1.02	
1	6	2	-1.55	
1	6	24	-0.92	
1	7	2	-1.45	
1	7	24	-0.72	
1	8	2	-1.25	
1	8	24	-0.12	
1	9	2	-1.48	
1	9	24	-0.07	
1	10	2	-1.28	
1	10	24	0.03	
1	11	2	-0.98	
1	11	24	-0.07	
1	12	2	-1.28	
1	12	24	-0.28	
1	13	2	-0.88	
1	13	24	-0.28	
1	14	2	-0.68	
1	14	24	-0.38	
1	15	2	-0.58	
1	15	24	-0.38	
1	16	2	-0.38	
1	16	24	-0.38	
1	17	2	-0.28	
1	17	24	-0.28	
1	18	2	-0.28	
1	18	24	-0.23	
1	19	2	-0.38	
1	19	24	-0.13	
1	20	2	-0.18	
1	20	24	-0.03	
1	21	2	-0.57	
1	21	24	0.07	
1	22	2	-1.57	
1	22	24	-0.03	
1	23	2	-1.54	
1	23	24	-0.01	
1	24	2	0.37	
1	24	3	0.57	
1	24	4	0.48	
1	24	5	0.48	
1	24	6	0.46	
1	24	7	0.76	
1	24	8	1.06	
1	24	9	0.97	
1	24	10	0.97	
1	24	11	0.87	
1	24	12	0.71	
1	24	13	0.21	
1	24	14	0.01	

1	24	15	-0.14
1	24	16	-0.14
1	24	17	-0.04
1	24	18	0.04
1	24	19	0.04
1	24	20	0.04
1	24	21	0.08
1	24	22	-0.12
1	24	23	0.44
1	24	24	-0.04
2	2	21	0.10
2	2	22	0.20
2	2	23	0.30
2	2	24	0.60
2	3	24	0.50
2	4	24	0.60
2	5	24	0.30
2	6	24	0.30
2	7	24	0.30
2	8	24	0.30
2	9	24	0.30
2	10	24	0.30
2	11	24	0.30
2	12	24	0.30
2	13	24	0.30
2	14	24	0.30
2	15	24	0.20
2	16	24	0.10
2	17	24	0.10

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